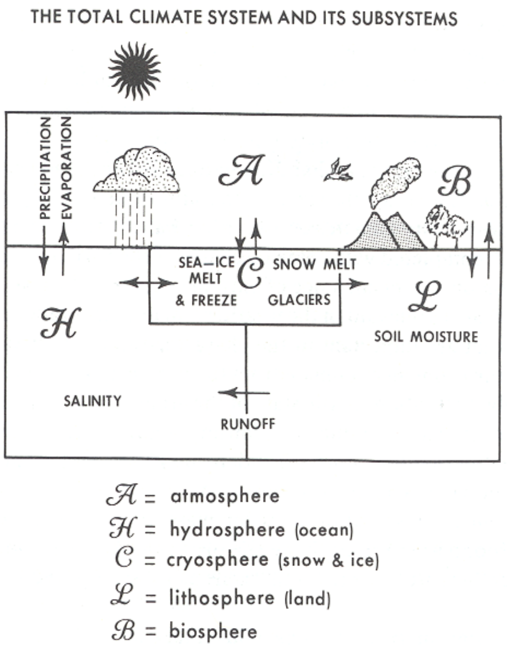
Impact of Climate Change on the Great Lakes Ecosystem

Jia Wang-- ***Jia.Wang@noaa.gov***

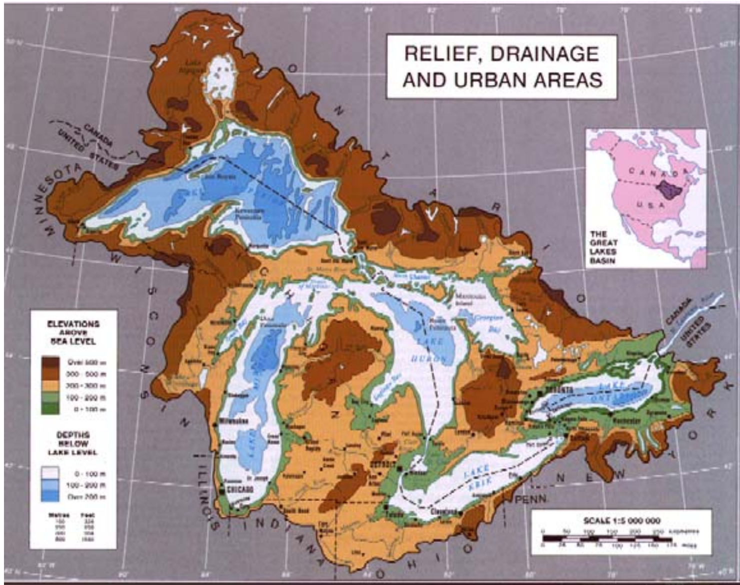


- ***What is the climate system?***
  The climate system is
  defined as $\boldsymbol{CS}=\boldsymbol{A}\cup\boldsymbol{H}\cup\boldsymbol{C}\cup\boldsymbol{L}\cup\boldsymbol{B}$

- ***Ecosystem is one subsystem of the climate system***

- ***The Great Lakes (watersheds) meet the perfect definition, as a mini-climate system***

- *Climatology~ at least 30 years*



Physical Environment

(forcings to the ecosystems: bottom-up effect from seasonal, interannual, decadal, and centennial time scales)

- Atmosphere: large-scale circulation (teleconnection patterns), local wind and storms, SLP, Precip/Evap, Ta, clouds, heat fluxes, …

- Hydrosphere/Ocean: freshwater runoff, lake circulation, rip currents, waves&storm surges/seiches, horizontal and vertical mixing (due to wind/storms, waves, and currents), Tw(x,y,z,t), seasonal vertical stratification, turbidity, sediment deposition/resuspension due to mixing, irradiances/light attenuation, heat storage, …

- Cryosphere: ice concentration, thickness, and flow, ice duration (breakup and freezeup dates), ice albedo, ice types (ice serves as an important indicator/barrier/insulator/interactor between the atmos., lakes and ecosystems, although it is thin and exists only in winter months!)

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  ice concentration,
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  (ice serves as an important indicator/barrier/insulator/interactor between the atmos., lakes and ecosystems, although it is thin and exists only in winter months!)

Motivation

- Ice cover shrinking → water level drop → less loading for shipping, ecosystems, recreation, …, → economy
- Ecosystem anomaly ← Ice anomaly ← local Twater&mixing&circulation ← local atmospheric circulation&Tair ← [large-scale (global or hemispheric) atmospheric teleconnection patterns (internal climate variability)

  + GHG emission (anthropogenic, man-made trend)] (bottom-up effect)

This panel covers:

- Dr. Xuezhi Bai, CILER/SNRE, UoM (Research Investigator): Interannual variability of lake ice and internal climate teleconnection patterns
- Dr. Eric Anderson, NRC Postdoc, GLERL: Hydrodynamic modeling and forecasting in the Great Lakes
- Dr. Jia Wang, GLERL: Coupled lake-ice modeling and projections of the Great Lakes climate in the 21st century;

Coupled lake-ice modeling
and
Projections of the Great Lakes climate in the 21st century

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CILER/UoM: **Haoguo Hu, Dima Belestky, Xuezhi Bai**

U. of Illinois: **Bill Chapman**

Outline

- **Coupled ice-lake modeling in the Great Lakes**
- **IPCC model projection**
- **Interannual variability of the Great Lake water temperature**
- **Ecosystem adaption**
- **Summary**

Motivation

Needs for prediction of lake ice using numerical models

- **No a single climate pattern (ENSO, NAO/AO) influencing the GL is dominating, so the predictability of sea ice based on climate pattern indices is poor (Assel and Rodionov 2001, 2002)**

- **Sediment resuspension and transport during winter storm and lake ice season (Schwab et al. 2006, Hawley et al. 2006); The GLERL's Great Lakes Coastal Forecast System (GLCFS) (without ice, a gap)**

  —Need lake ice coupled to an hydrodynamic-sediment model

- **Biogeochemical/ecosystems modeling such as hypoxia—Multiple stressors (Chen et al. 2004)**

  —Need hydrodynamic-ice circulation model

- **Regional climate model in the Great Lakes (Lofgren 2005)**

  —Need lake ice model to predict radiation/nergy balance/feedback to the atmosphere, and lake water level (Assel, Quinn&Sellinger 2004)

- **Great Lakes as a platform for INTERDISCIPLINARY research in a "mini climate system": Atmosphere, hydrosphere/hydrodynamics, lake ice, biosphere/ecosystem, and lithosphere (land processes, hydrology, coastal erosion)**

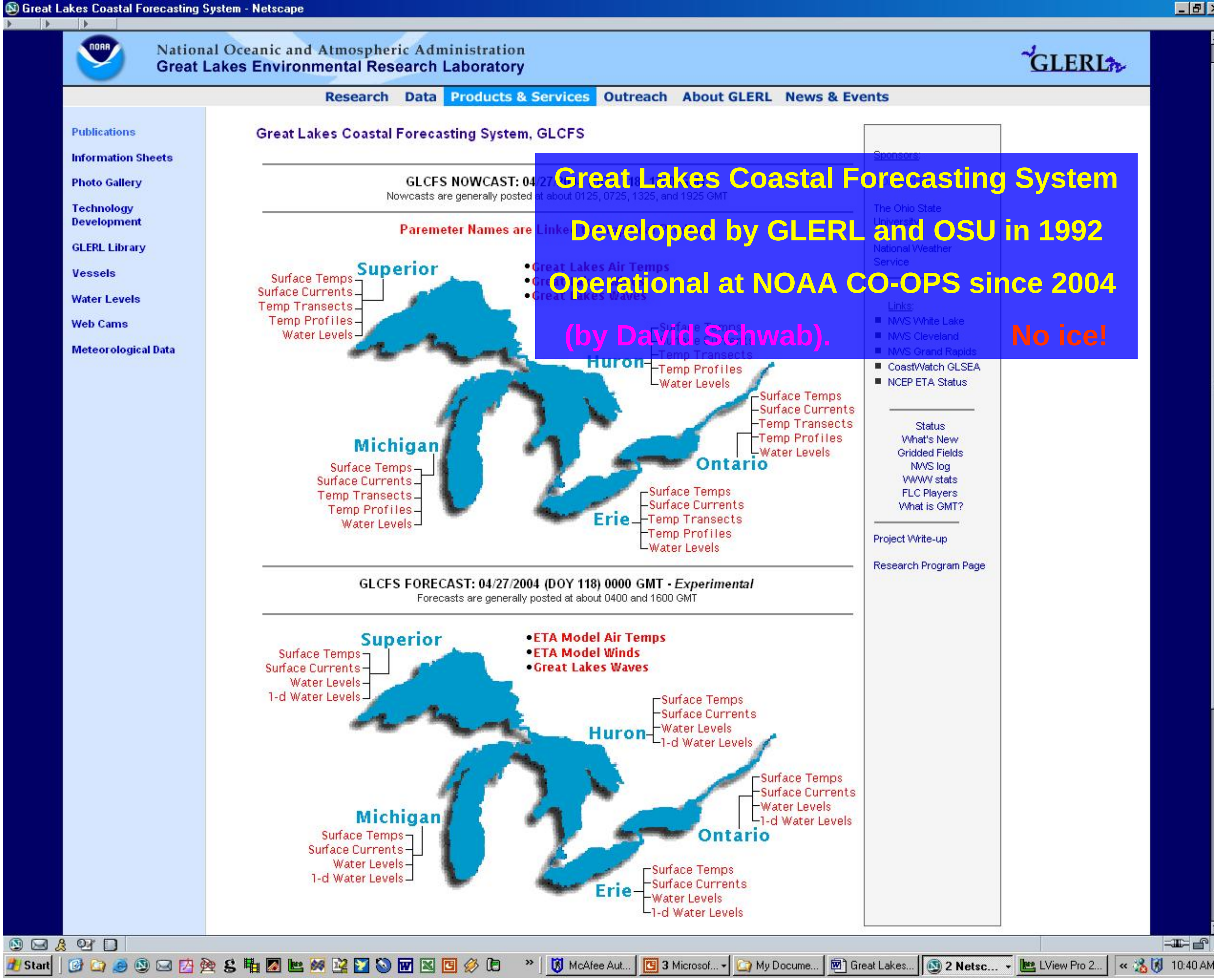
  —Need lake ice component

Great Lakes Coastal Forecasting System

Developed by GLERL and OSU in 1992

Operational at NOAA CO-OPS since 2004

(by David Schwab). **No ice!**

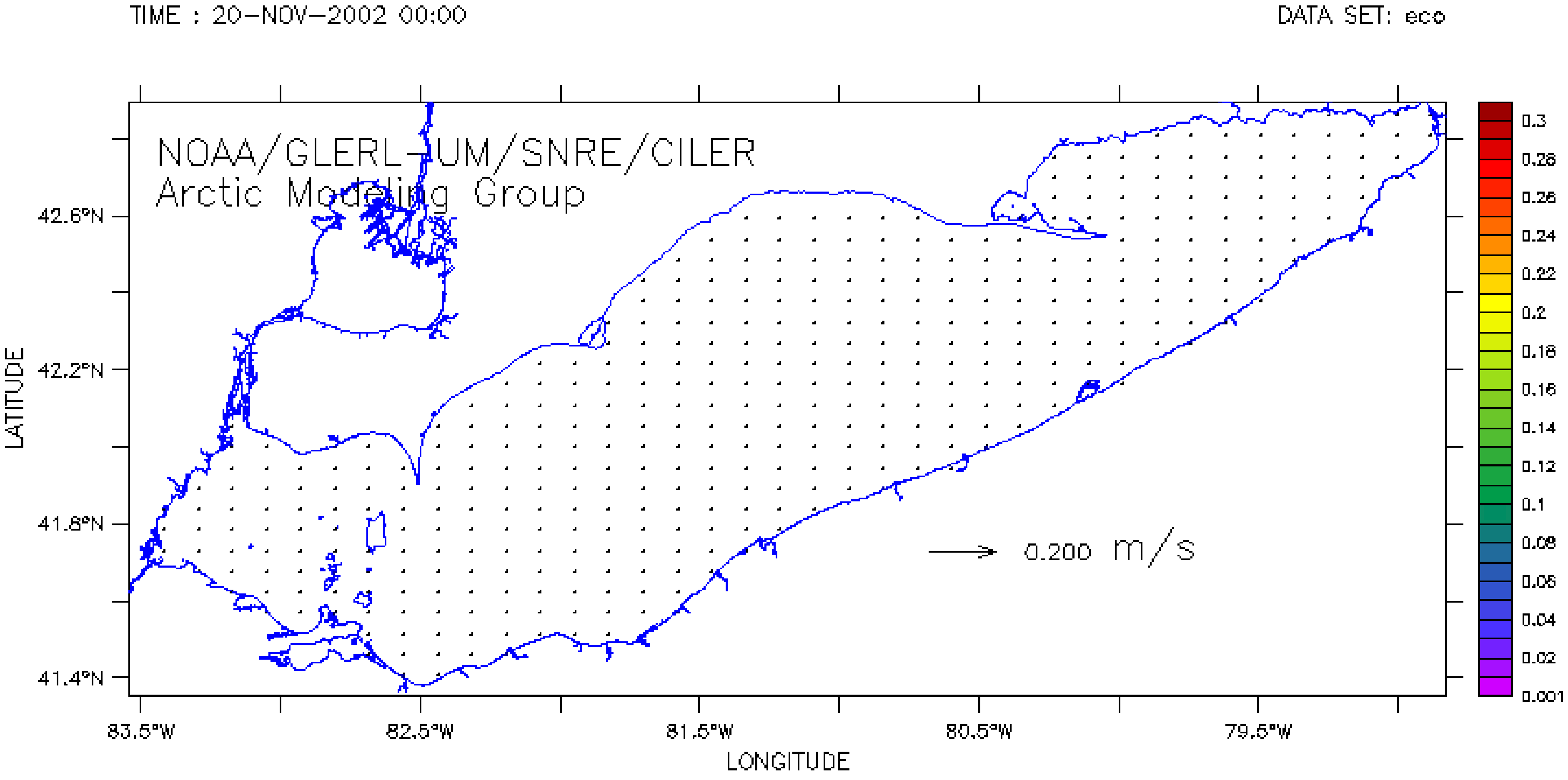


GLIM in Lake Erie

based on CIOM (Wang et al. 2002, 05, 08)

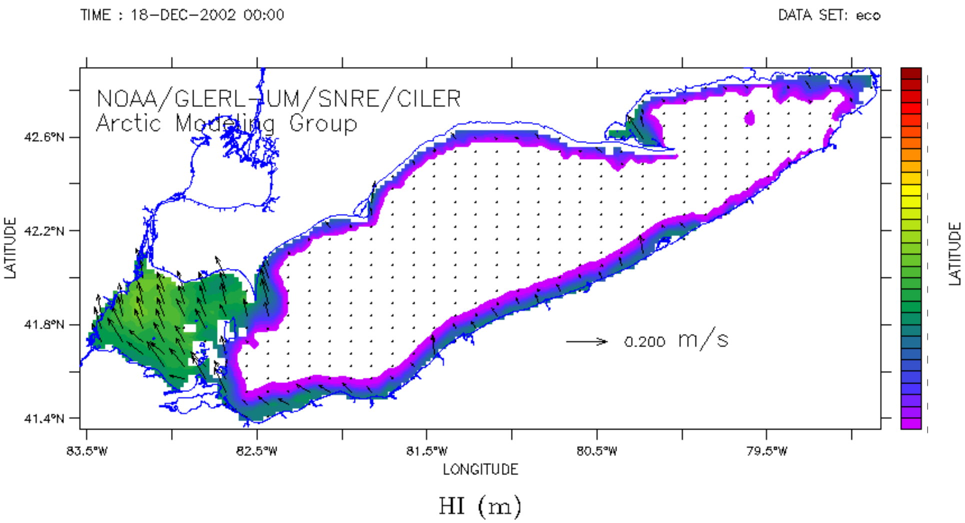
1. POM (Mellor 2001)
2. Multicategory sea ice model (Yao et al., 2000; Wang et al. 2002, 2005, 2008) based on: two-layer ice thermodynamics with 1-layer snow, ice dynamics with viscous-plastic rheology
3. 2-km in Lake Erie similar to GLCFS
4. 22 vertical sigma layers.
5. Daily atmospheric forcing from NCEP/NCAR daily forcing fields (air temperature and humidity at 2m, wind at 10m), solar radiation and air longwave radiation
6. Initial (T/S) fields from measurements

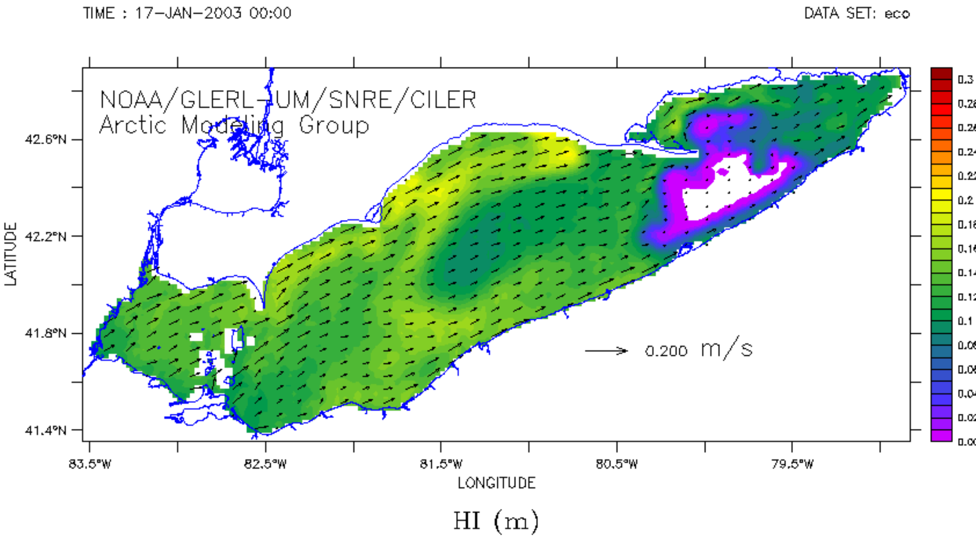
The Great Lakes Ice Model (GLIM): Ice velocity and thickness

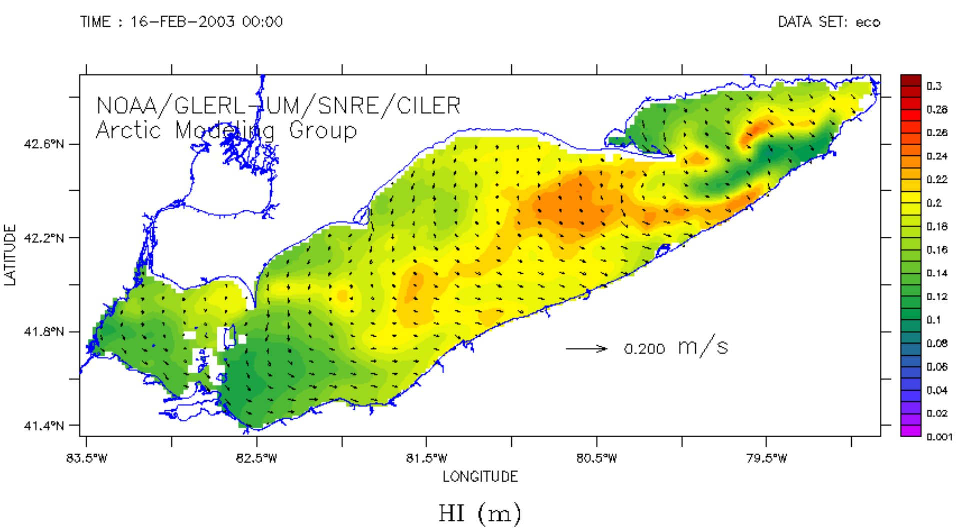


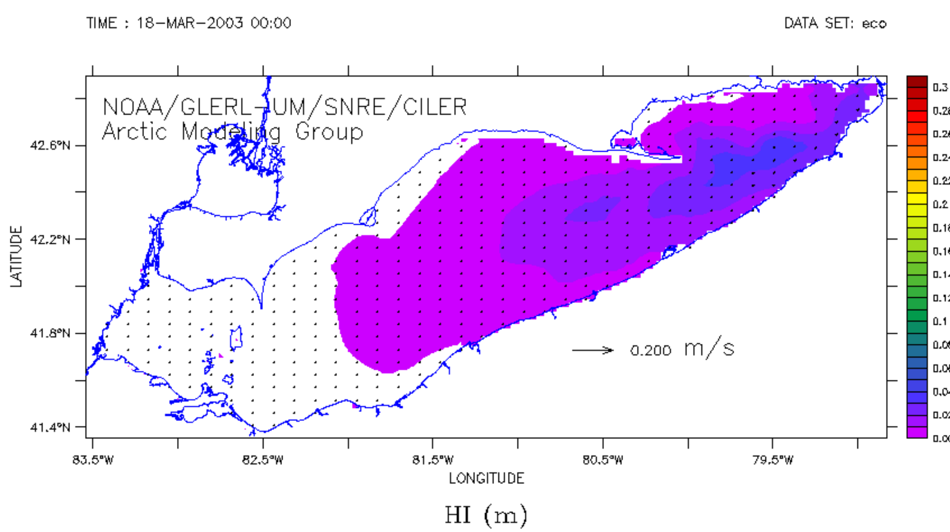
HI (m)

Seasonal cycle of ice thickness

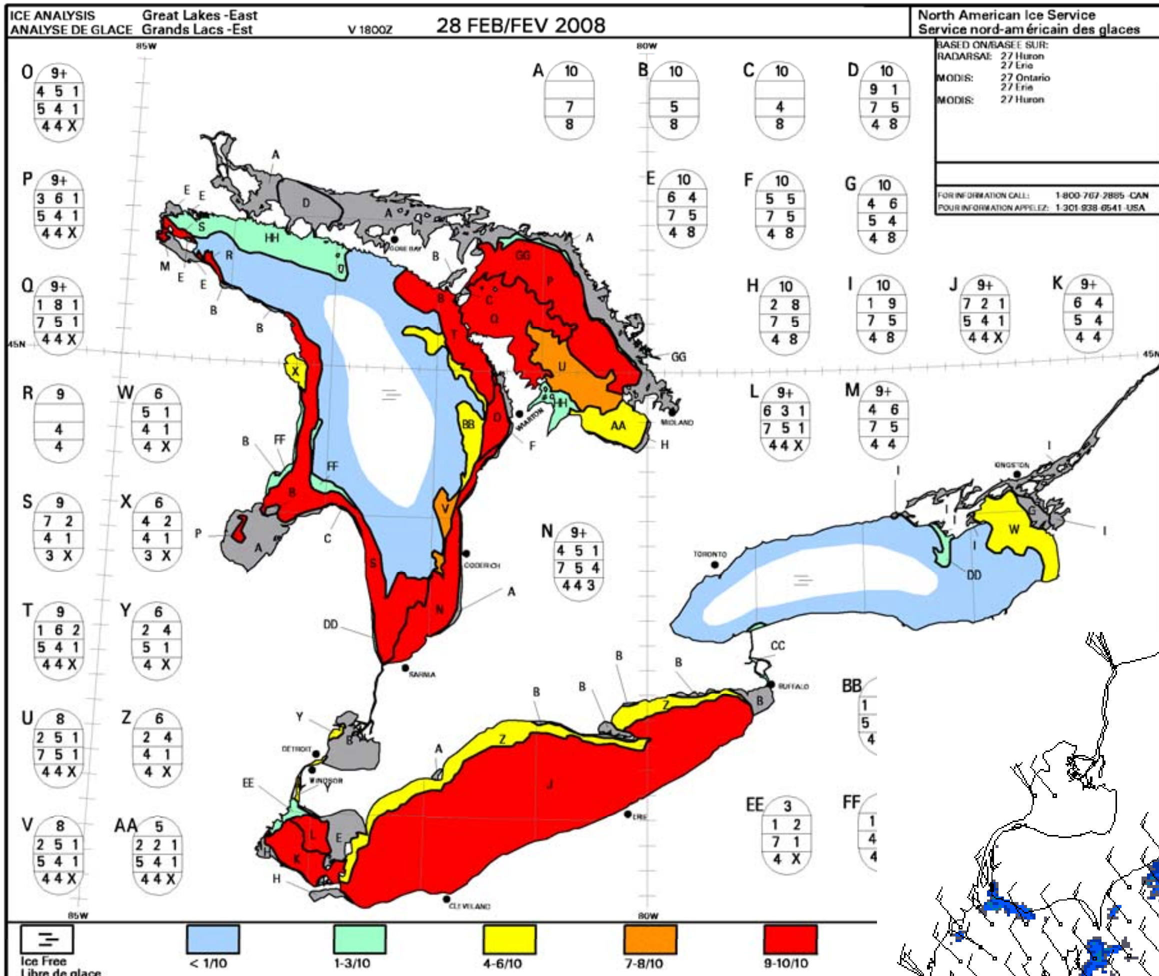


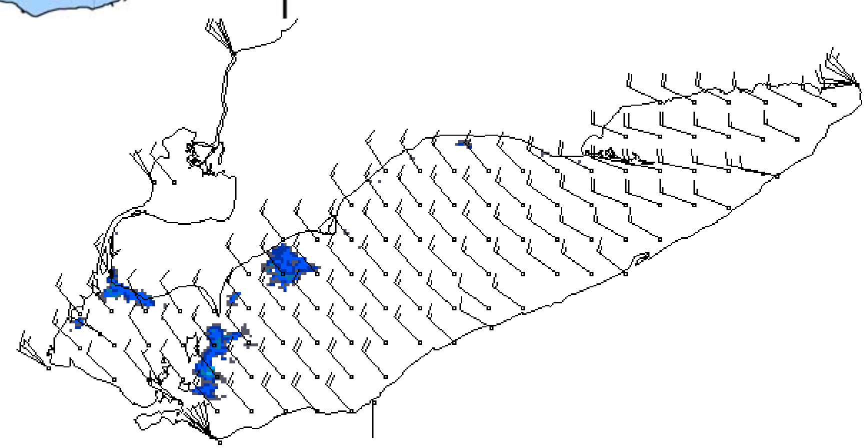




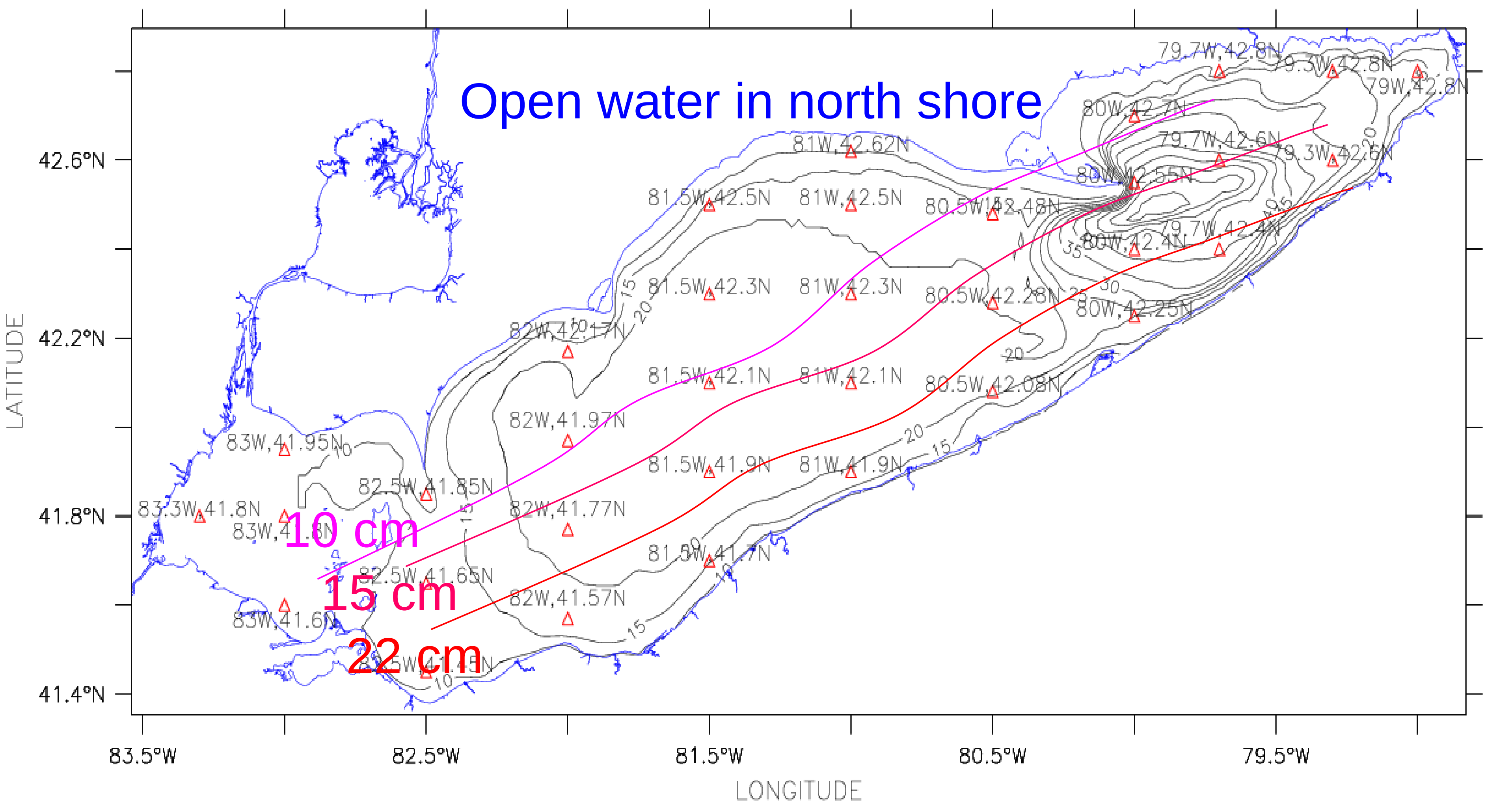


Lake Ice Extent on Feb 28, 2008

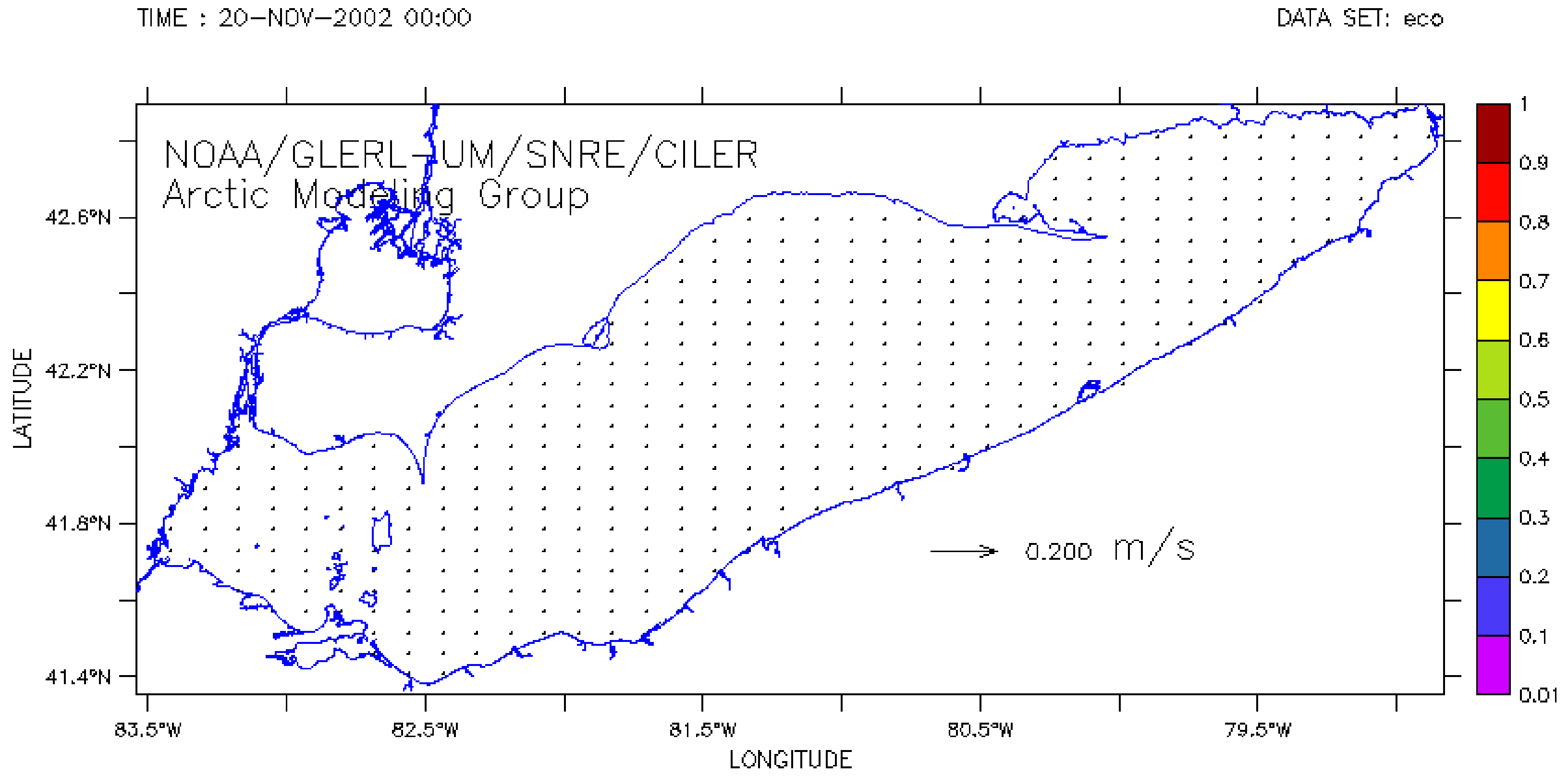




2008 Feb-27 GLERL-USCG Ice Thickness Measurement Stations



Ice velocity and concentration (compactness)



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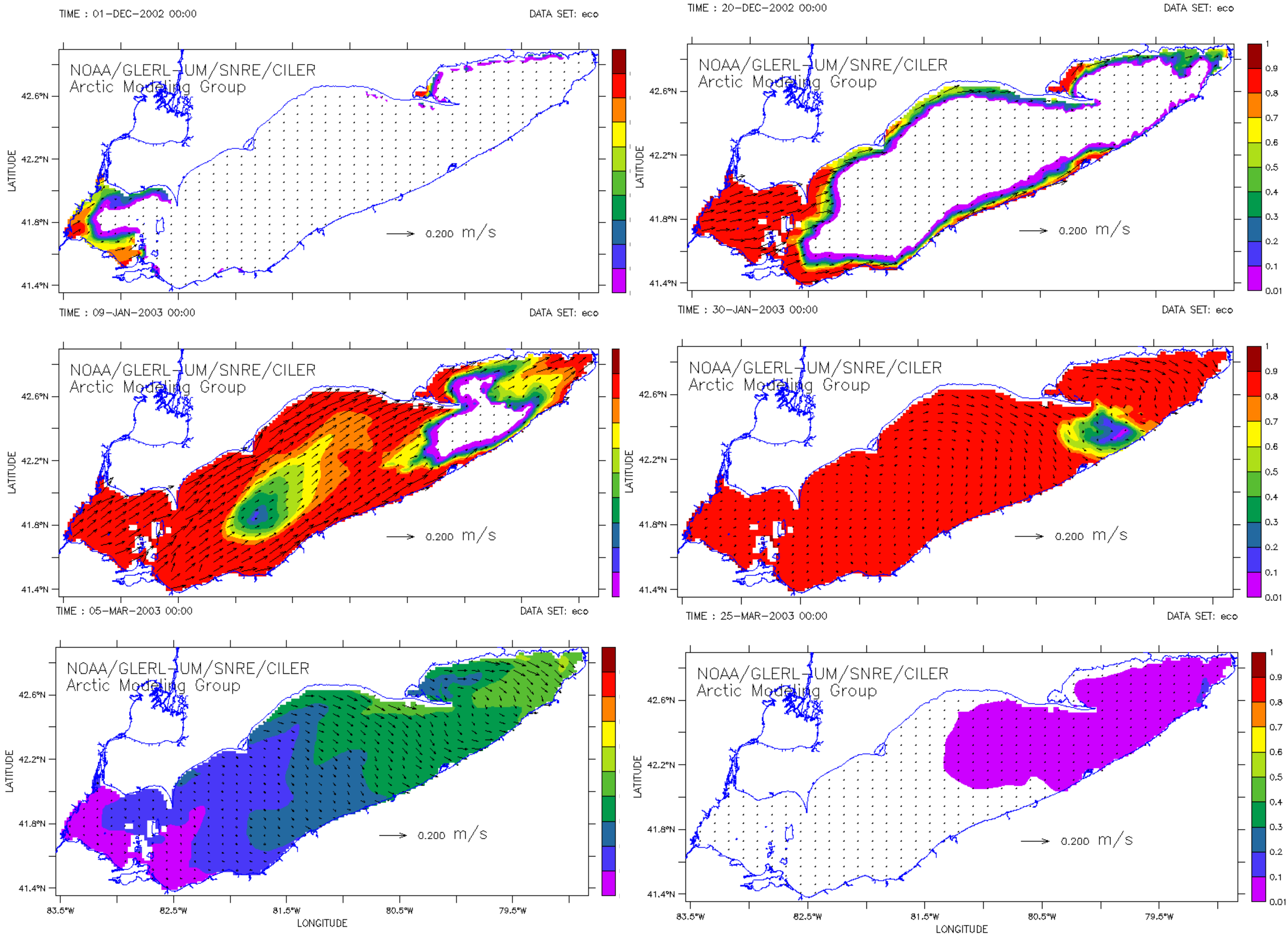
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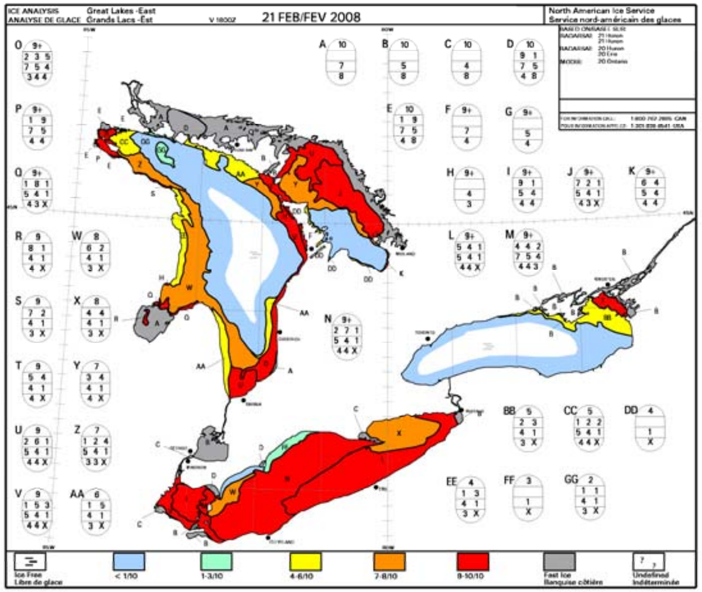
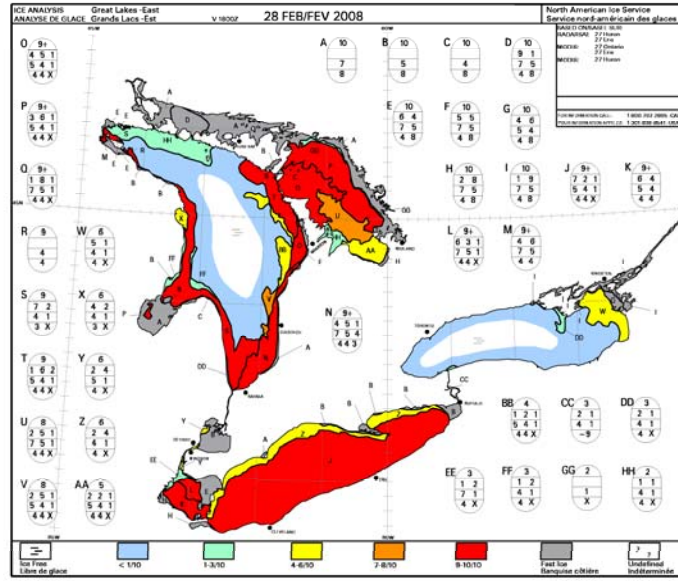
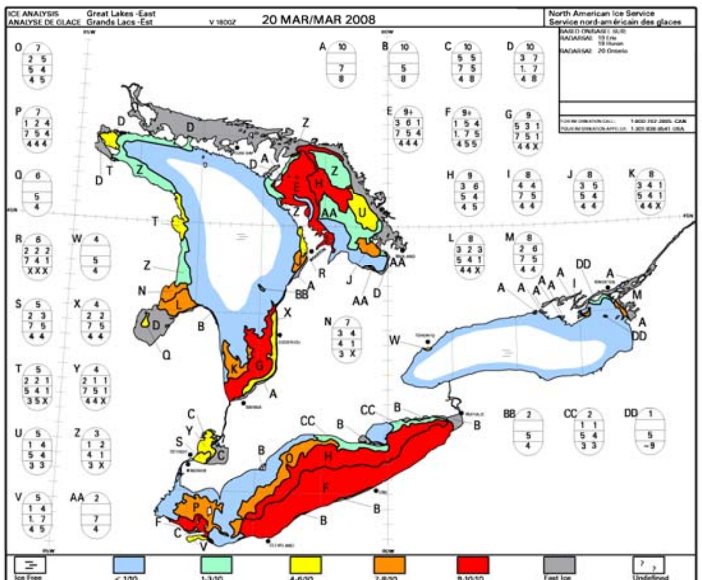
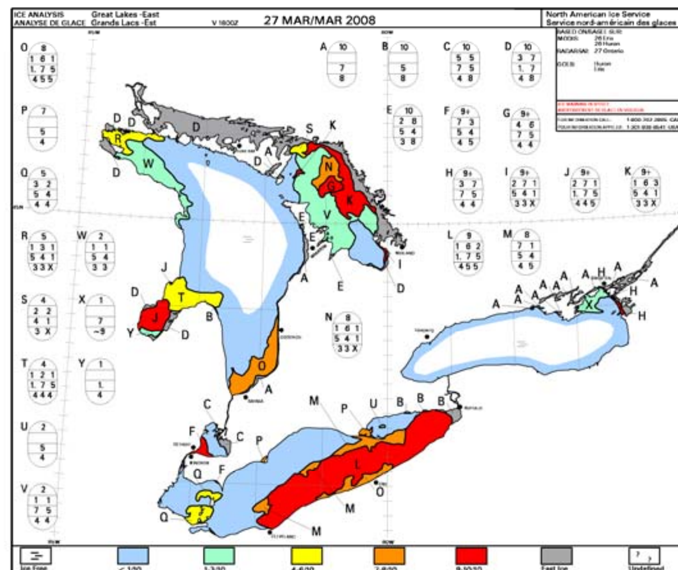
TIME : 20-DEC-2002 00:00
DATA SET: eco
TIME : 09-JAN-2003 00:00
DATA SET: eco
TIME : 30-JAN-2003 00:00
DATA SET: eco
TIME : 05-MAR-2003 00:00
DATA SET: eco
TIME : 25-MAR-2003 00:00
DATA SET: eco
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.200 m/s
LATITUDE
LONGITUDE
42.6°N
42.2°N
41.8°N
41.4°N
83.5°W
82.5°W
81.5°W
80.5°W
79.5°W
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.01

2008 Ice Season in Lake Erie

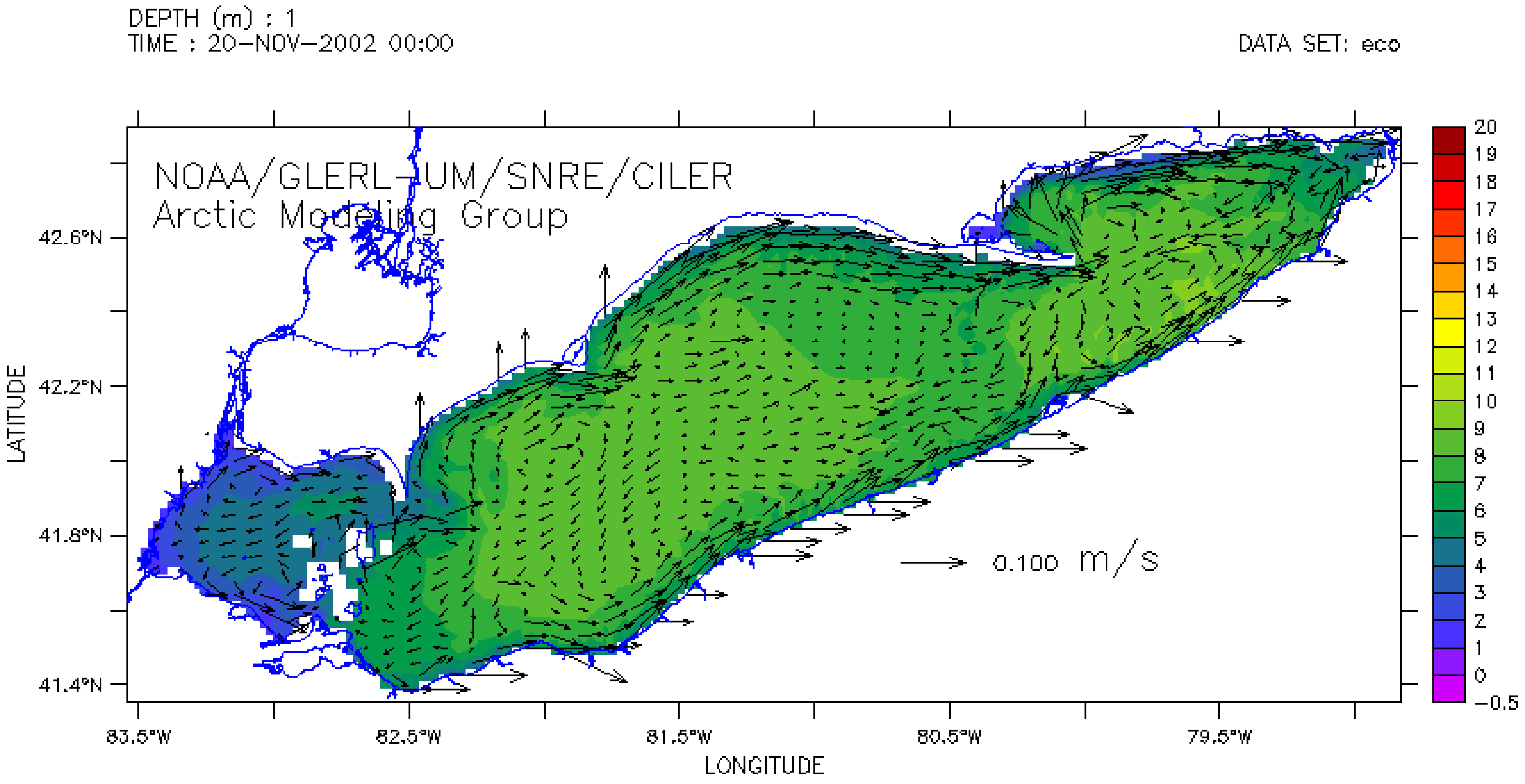




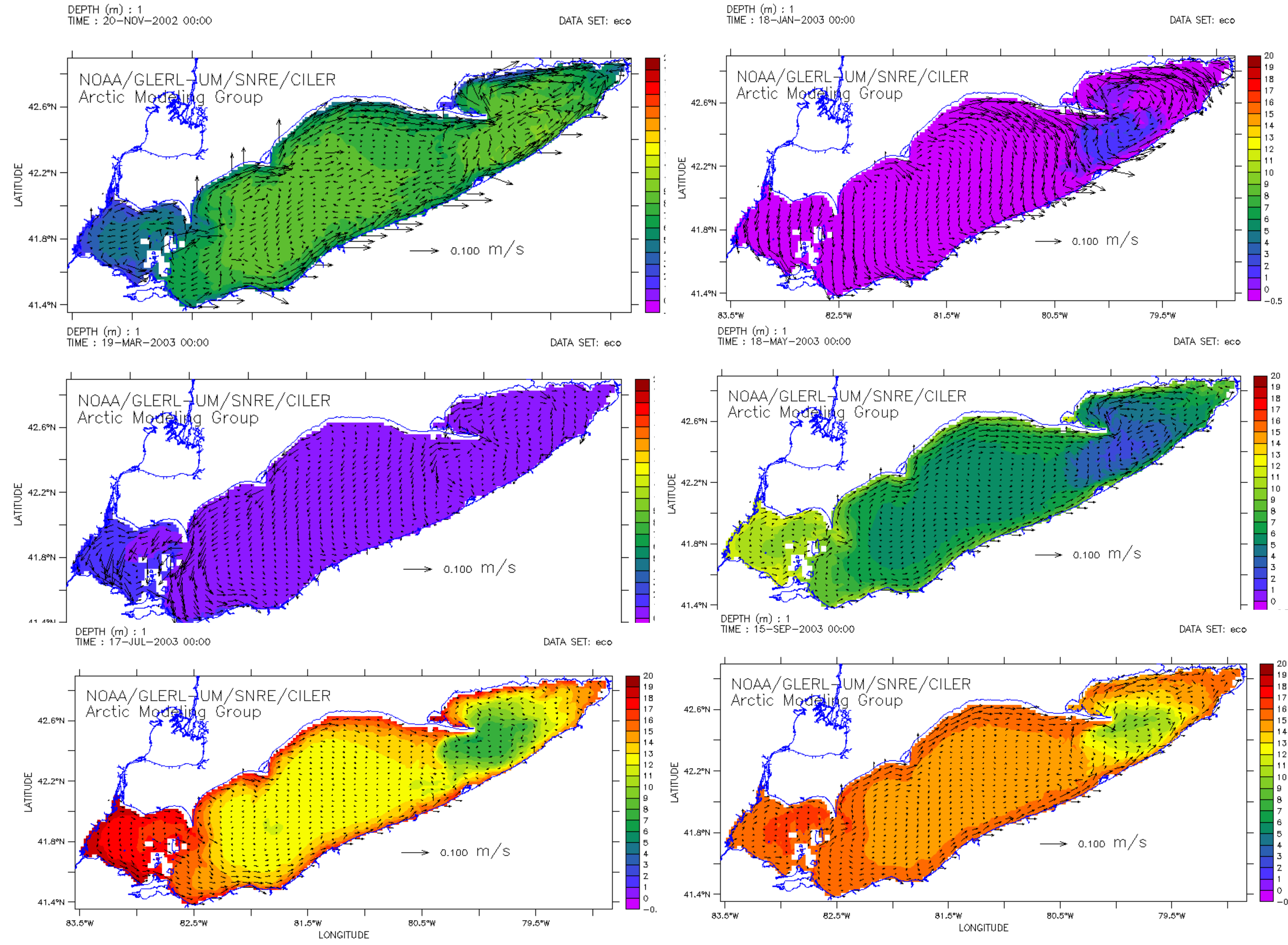




Lake surface velocity and lake surface temperature



TEM (Celsius)



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NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.100 m/s
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TIME : 18-JAN-2003 00:00
DATA SET: eco
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.100 m/s
DEPTH (m) : 1
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DATA SET: eco
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.100 m/s
DEPTH (m) : 1
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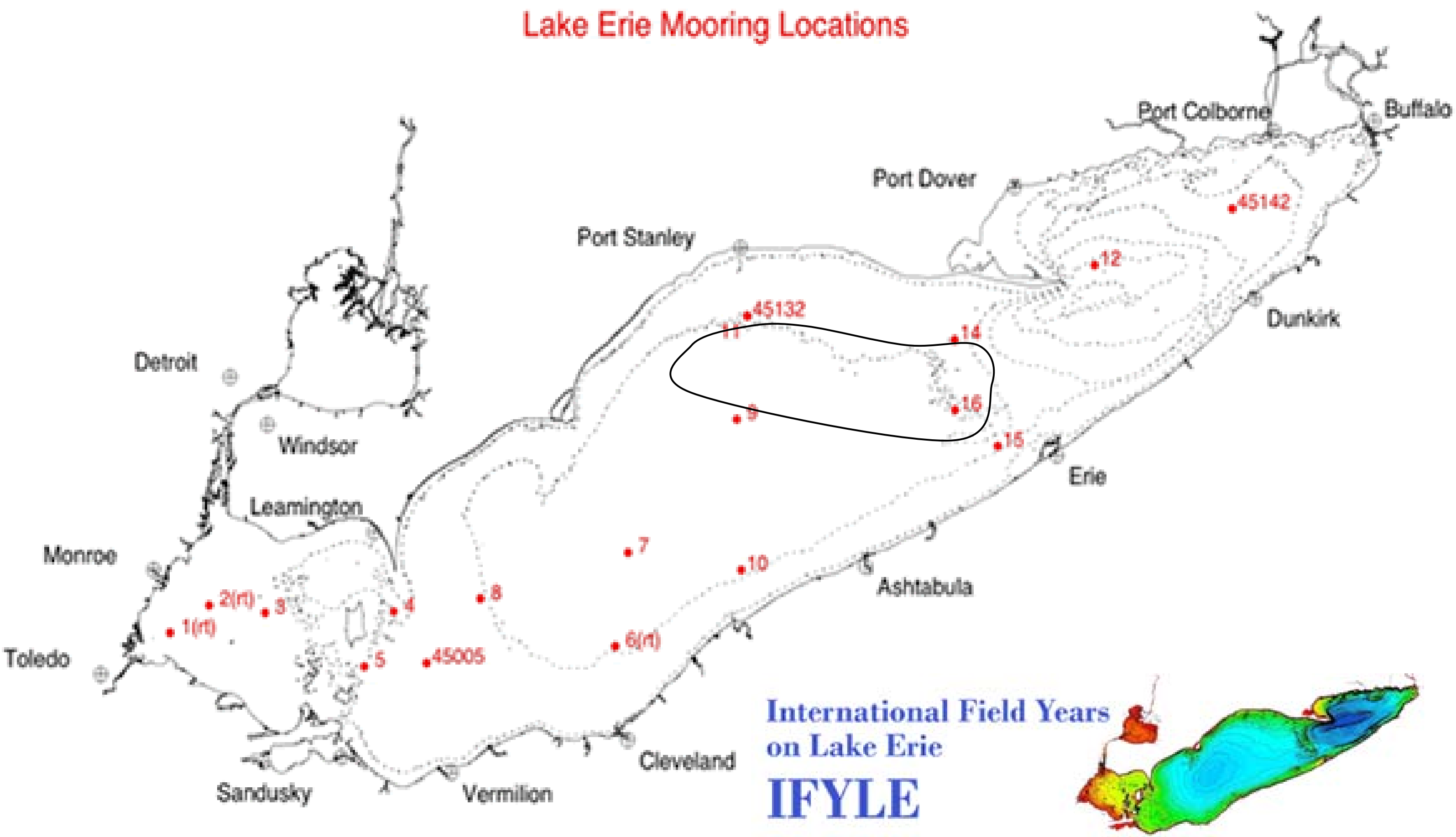
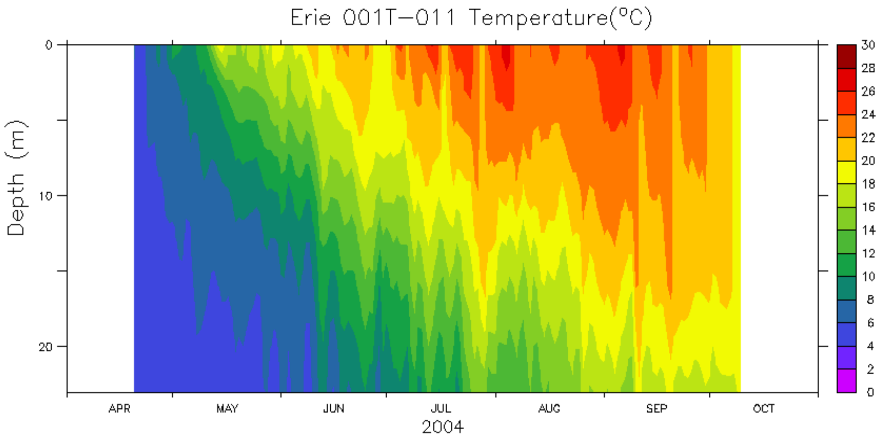
DATA SET: eco
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.100 m/s
DEPTH (m) : 1
TIME : 17-JUL-2003 00:00
DATA SET: eco
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.100 m/s
DEPTH (m) : 1
TIME : 15-SEP-2003 00:00
DATA SET: eco
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.100 m/s
LATITUDE
LONGITUDE
41.4°N
41.8°N
42.2°N
42.6°N
83.5°W
82.5°W
81.5°W
80.5°W
79.5°W

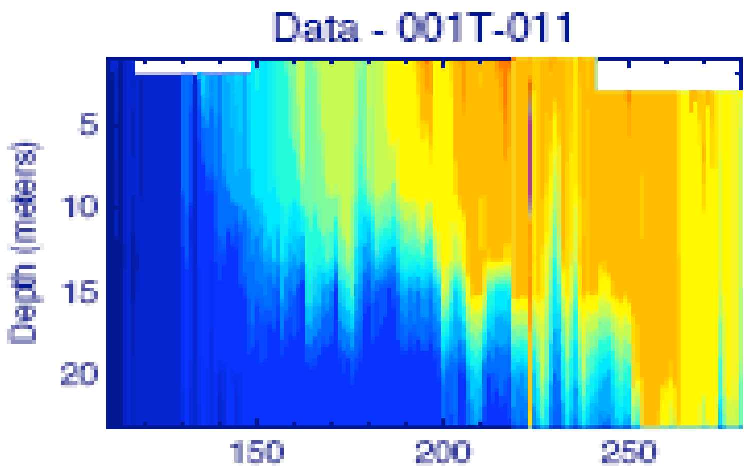
Model-data comparison

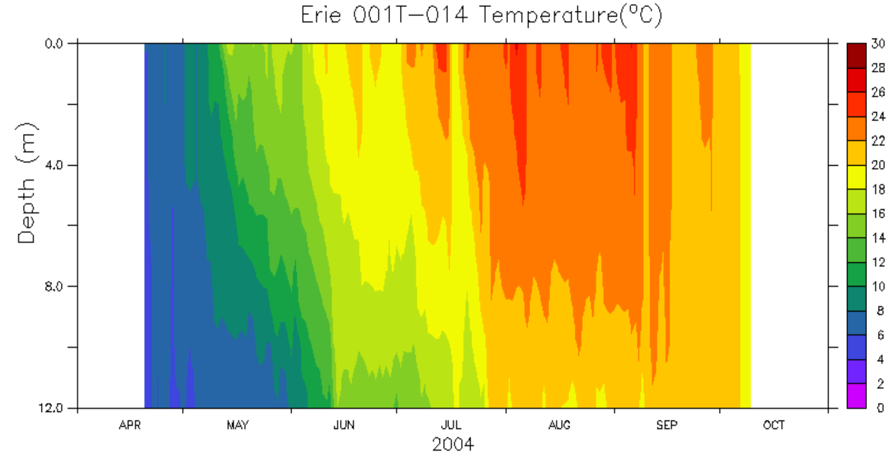


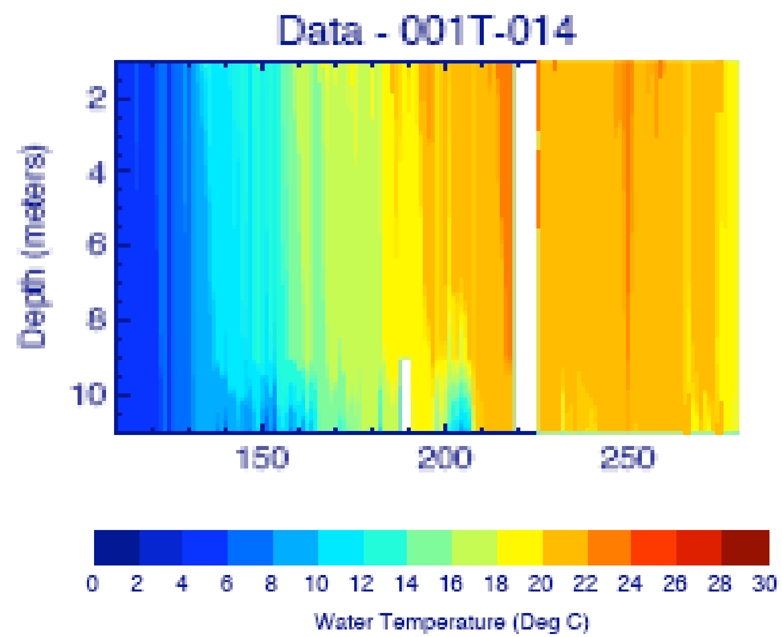
(

+ NDBC Eastern Great Lakes Marine Data web page)



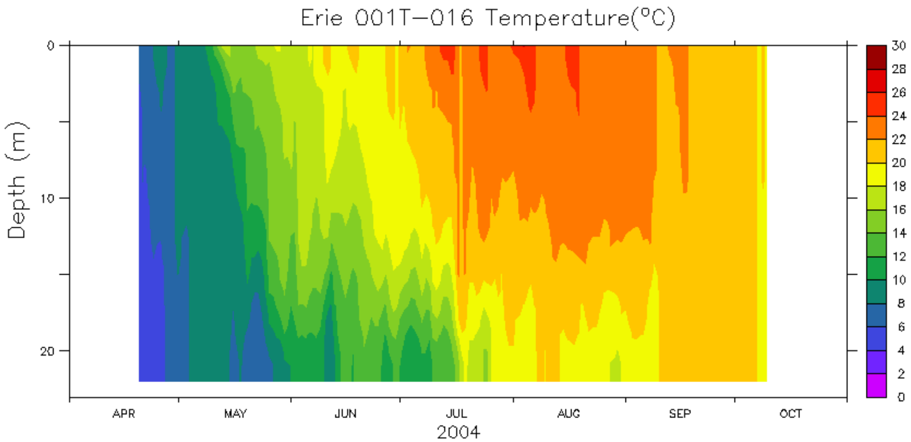


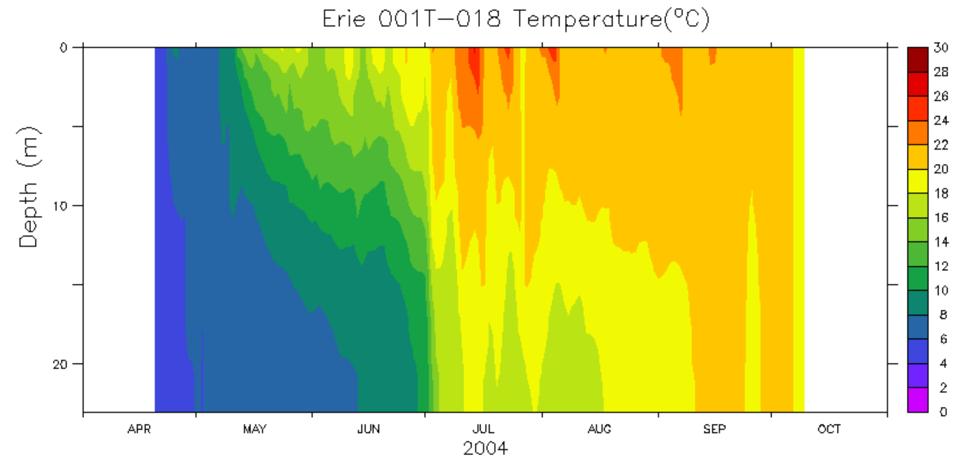


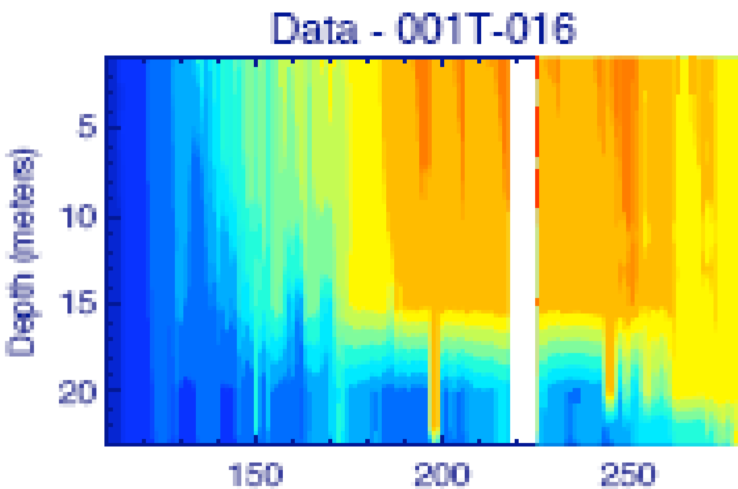


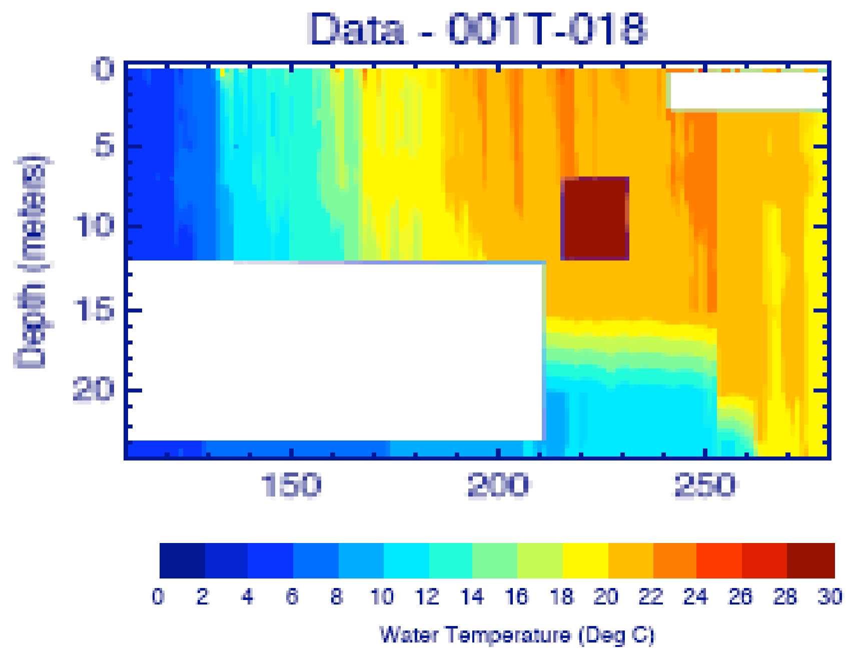
GLIM model simulation

From Dima Beletsky









GLIM model simulation

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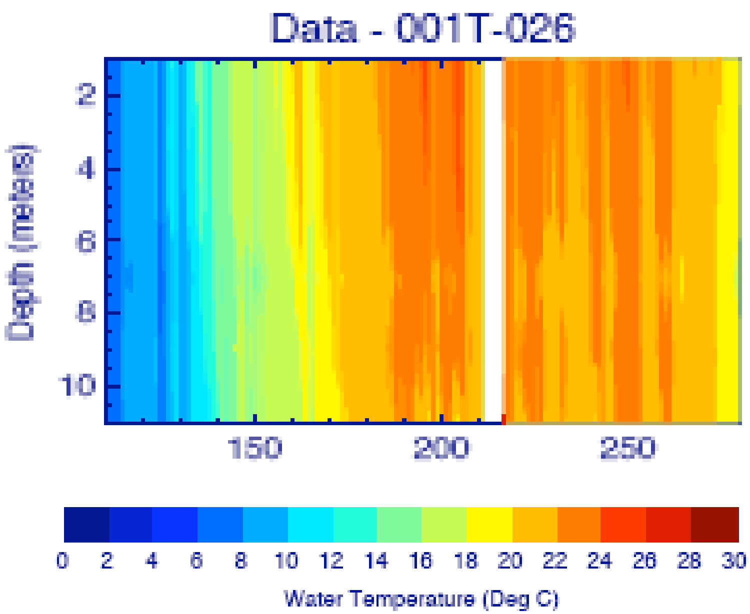
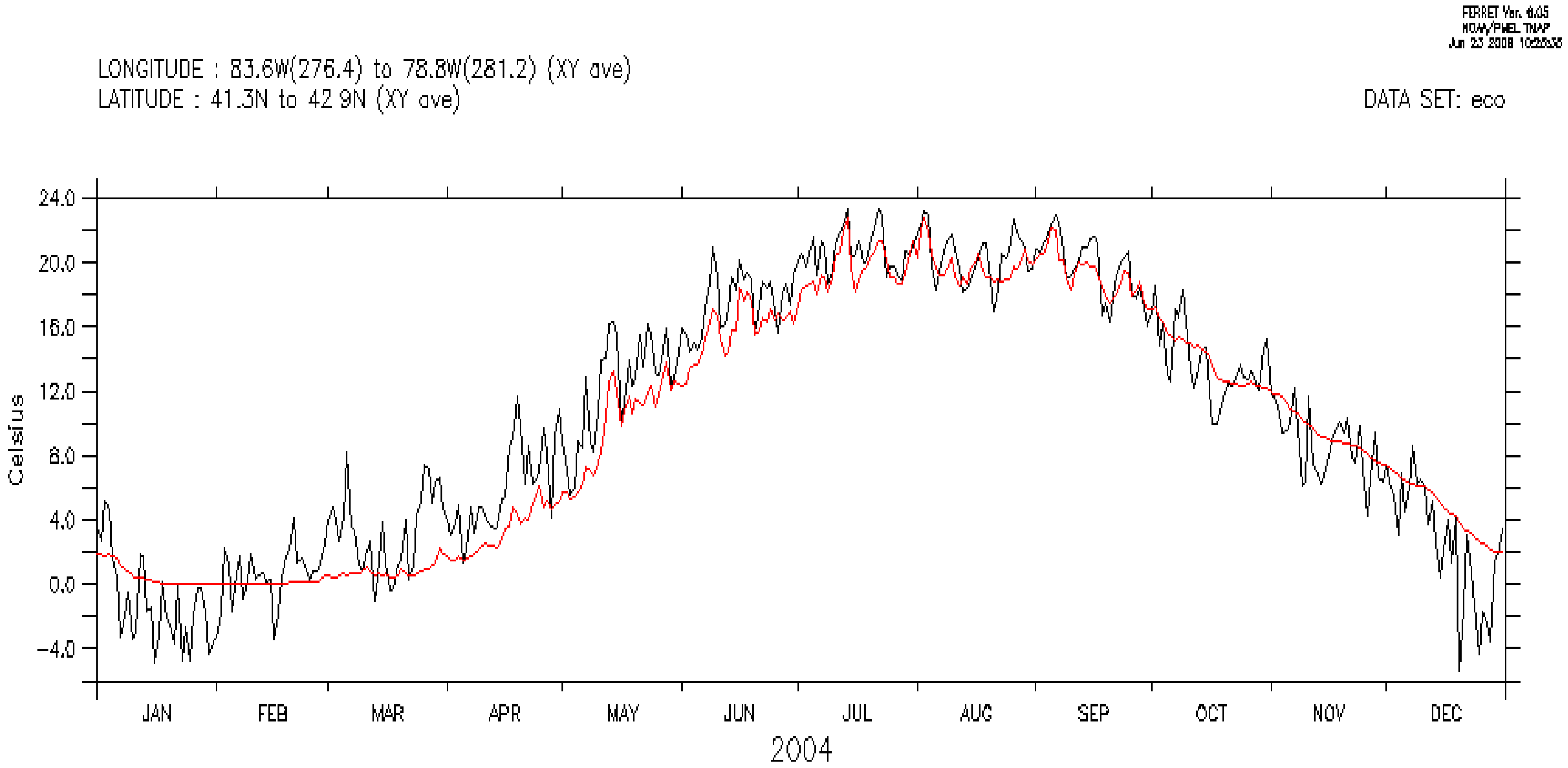


GLIM model simulation

From Dima Beletsky

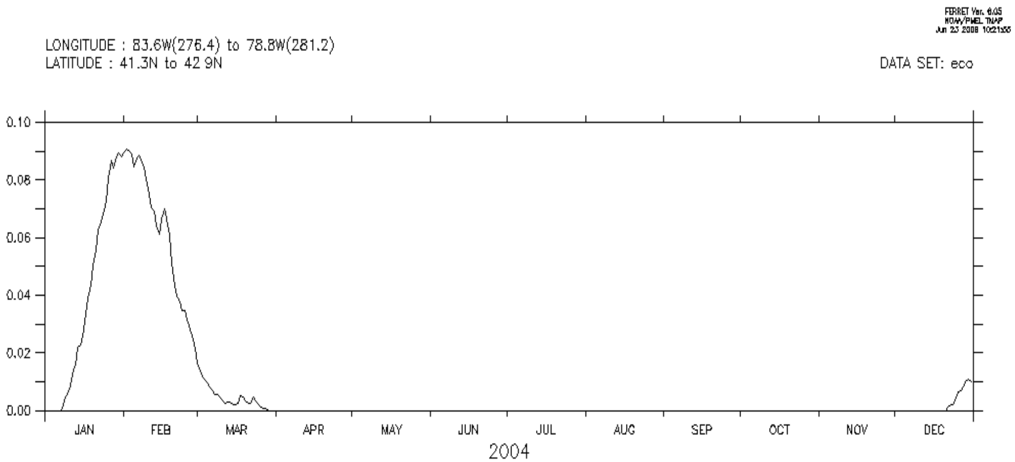
Toward a Forecast System

Hourly atmospheric forcing

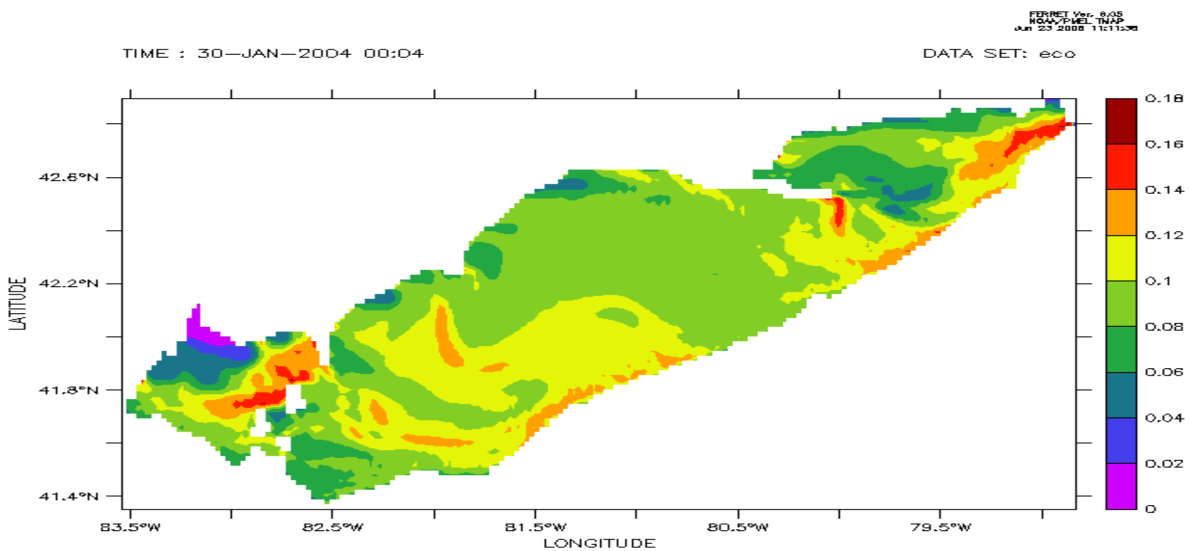


Air temperature(black) and water surface temperature(red)

Sea ice thickness

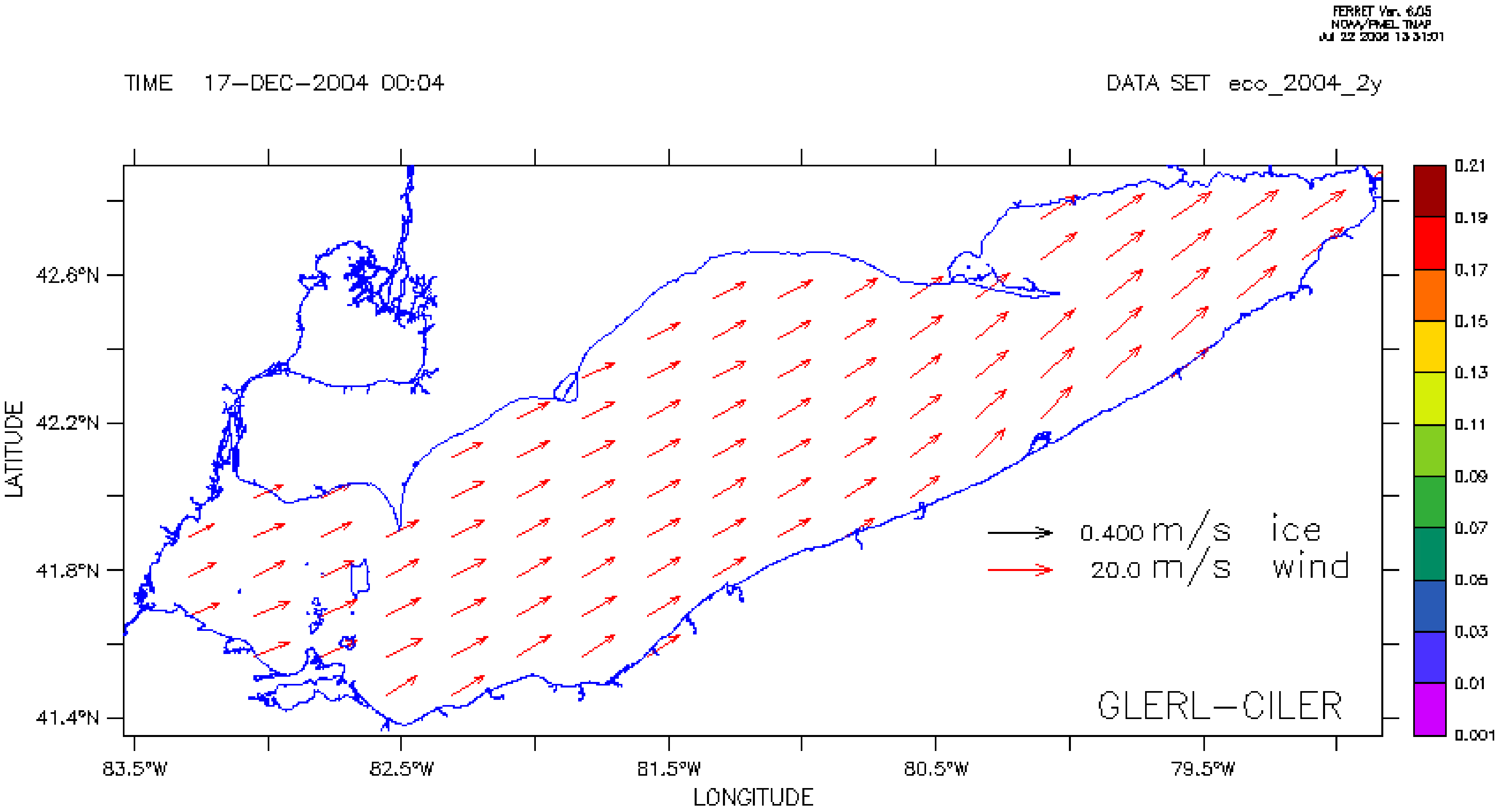


Average ice thickness



ice thickness

Simulated ice thickness+ice velocity, inserted by wind velocity



Summary

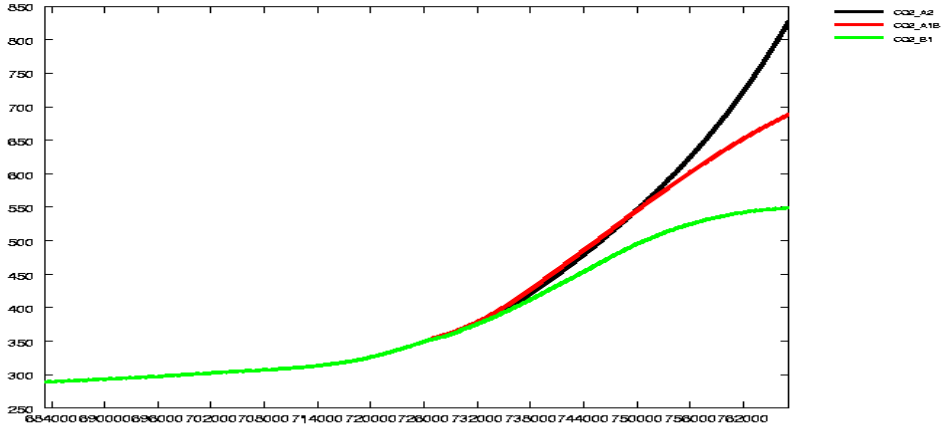
- Lake ice seasonal cycles are successfully reproduced, but needs for solid validation of GLIM, plan for 2004-05 ice season (IFYLE obs.), and 2007-08 season (ice thickness obs.) using hourly atmospheric forcing
- Model-model intercomparison shows GLIM lake-hydrodynamic model can reproduce similar results to the GLCFS

Future efforts:

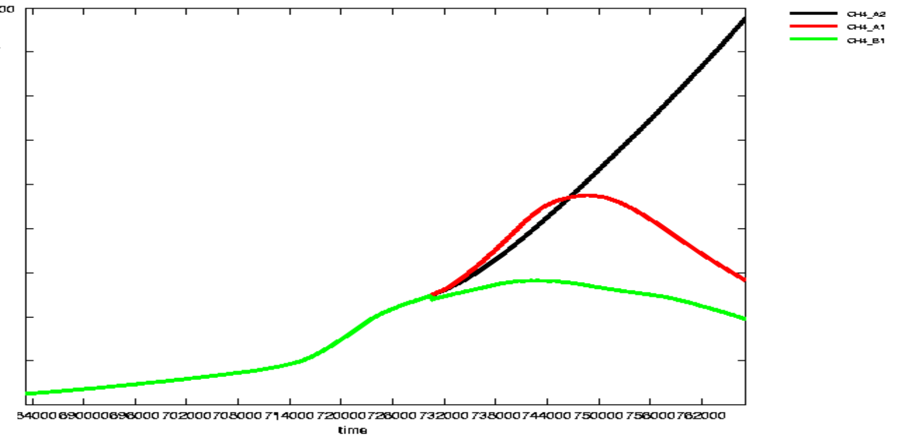
- Transformed GLIM to GLERL (Schwab) GLCFS
- Expanded to other Lakes
- Applied to Interannual variability of lake ice in Lake Erie
- Applied to ecosystem modeling

IPCC model projection of Great Lakes climate in the 21st century

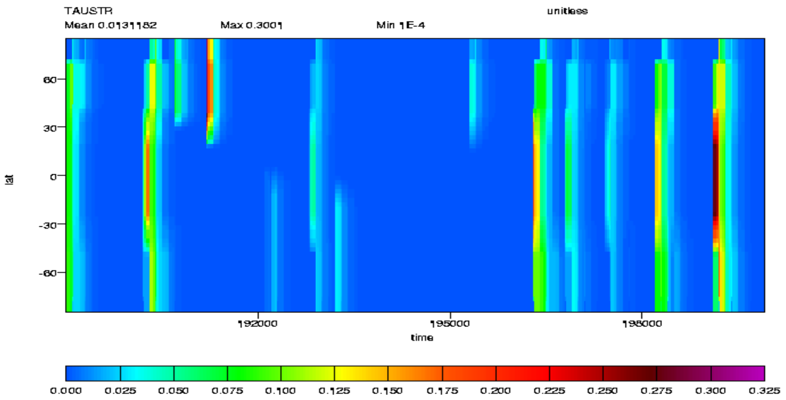
Greenhouse gases (GHG) emission: A1 (high end range: fossil fuels and rapid growth in 21st), A2 (upper mid-range: tech. changed slowly) and B1 (low end of rang: global solution to economic, social and environmental sustainability, clean, efficient tech.) Scenarios



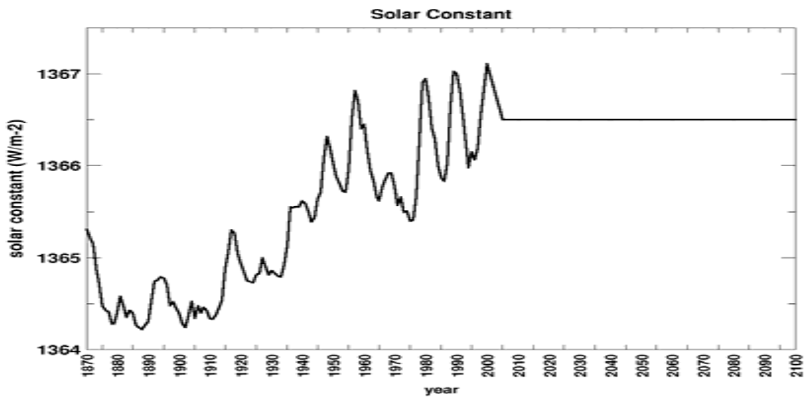
CO2



CH4

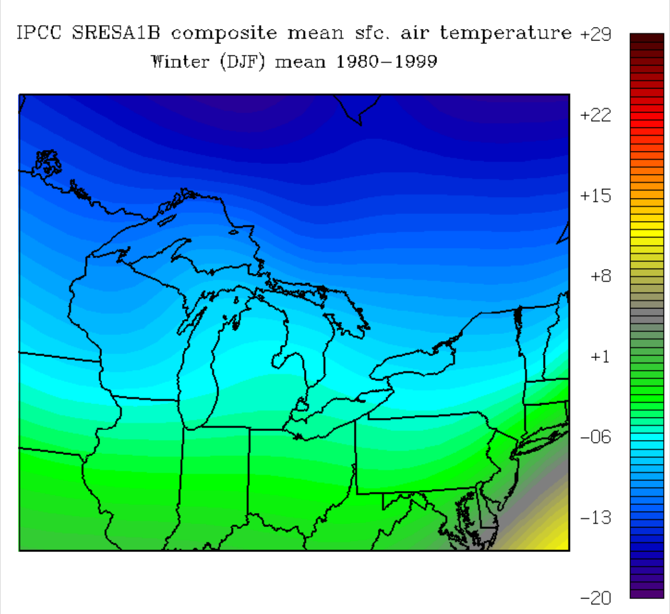


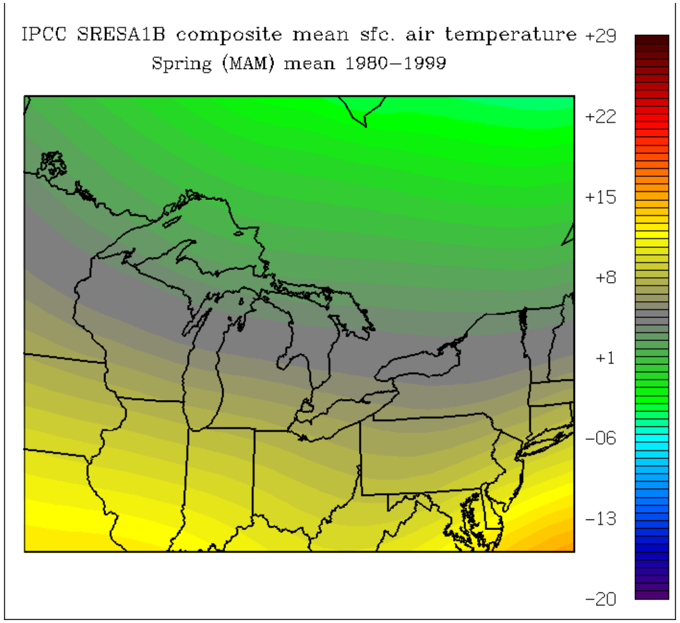
Volcano aerosols



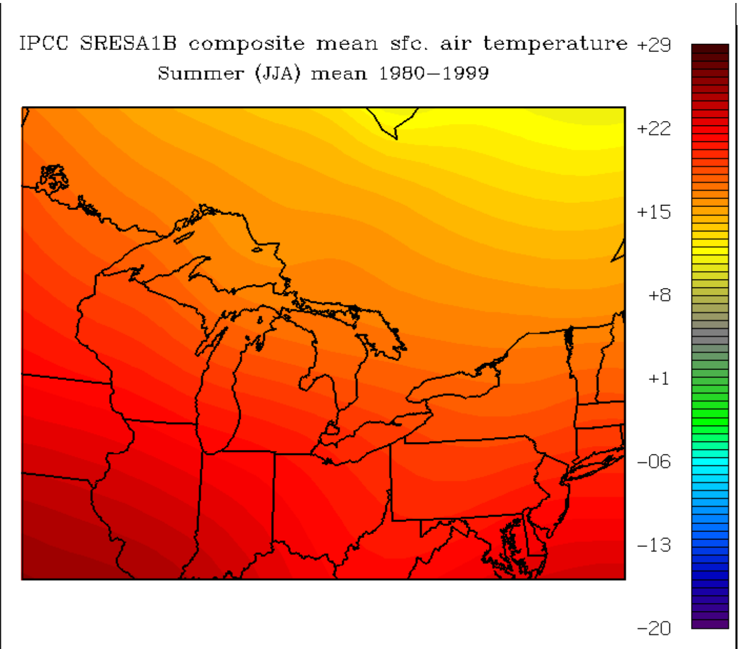
Solar constant

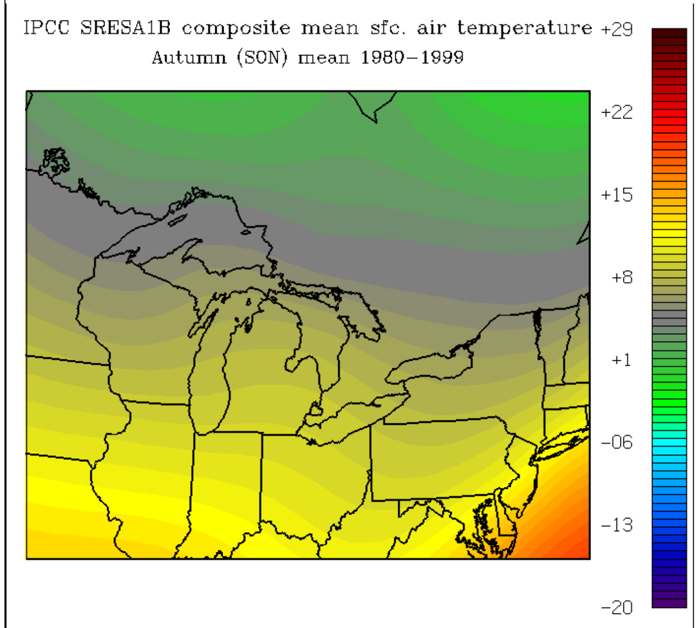
Climatology of Tair: 1980-1999





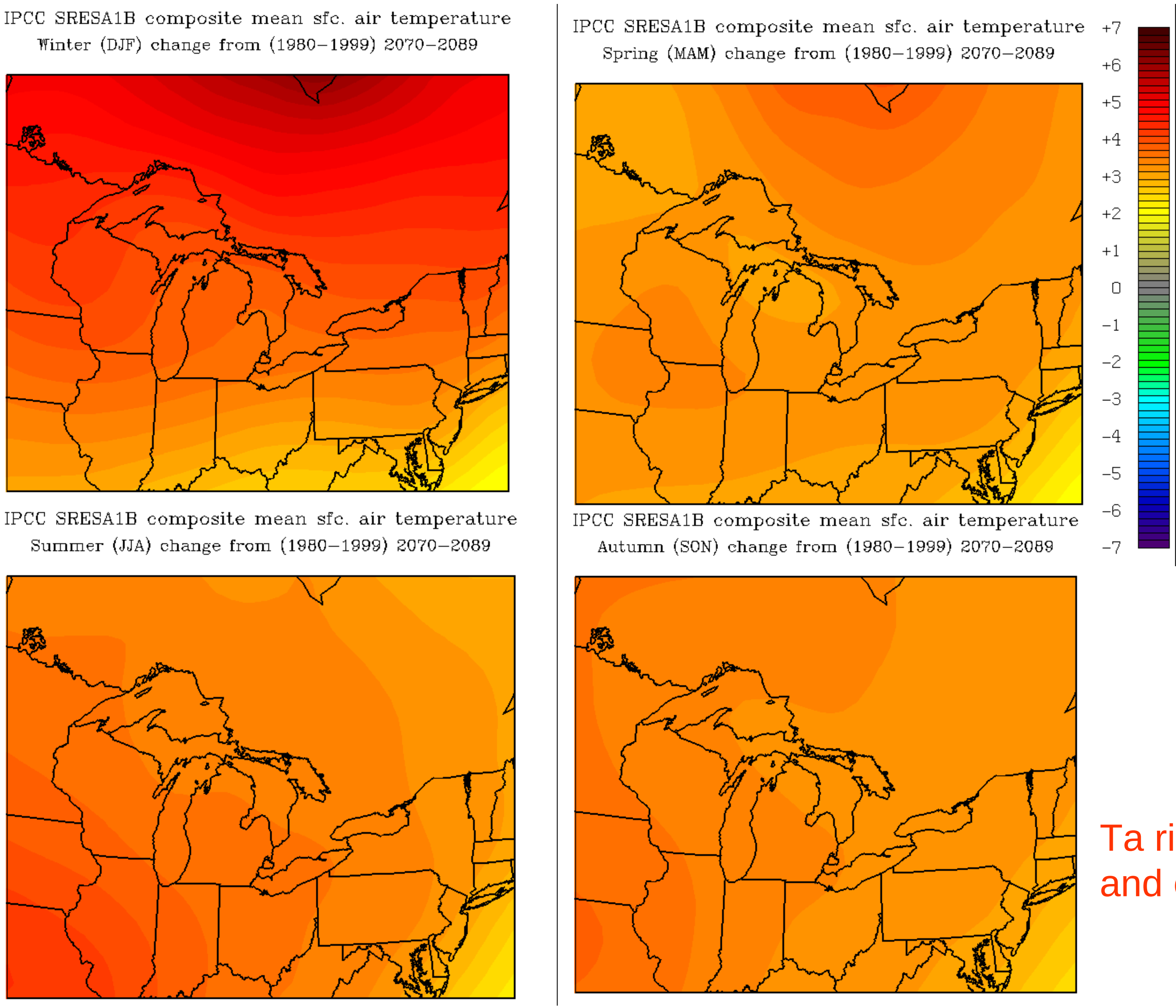
Winter Spring
-6 to -10 6 to 1C





Summer Autumn
20 to16 9 to 3 C

Tair anomaly projection: 2070-2089, (A1B)



Winter ~4C

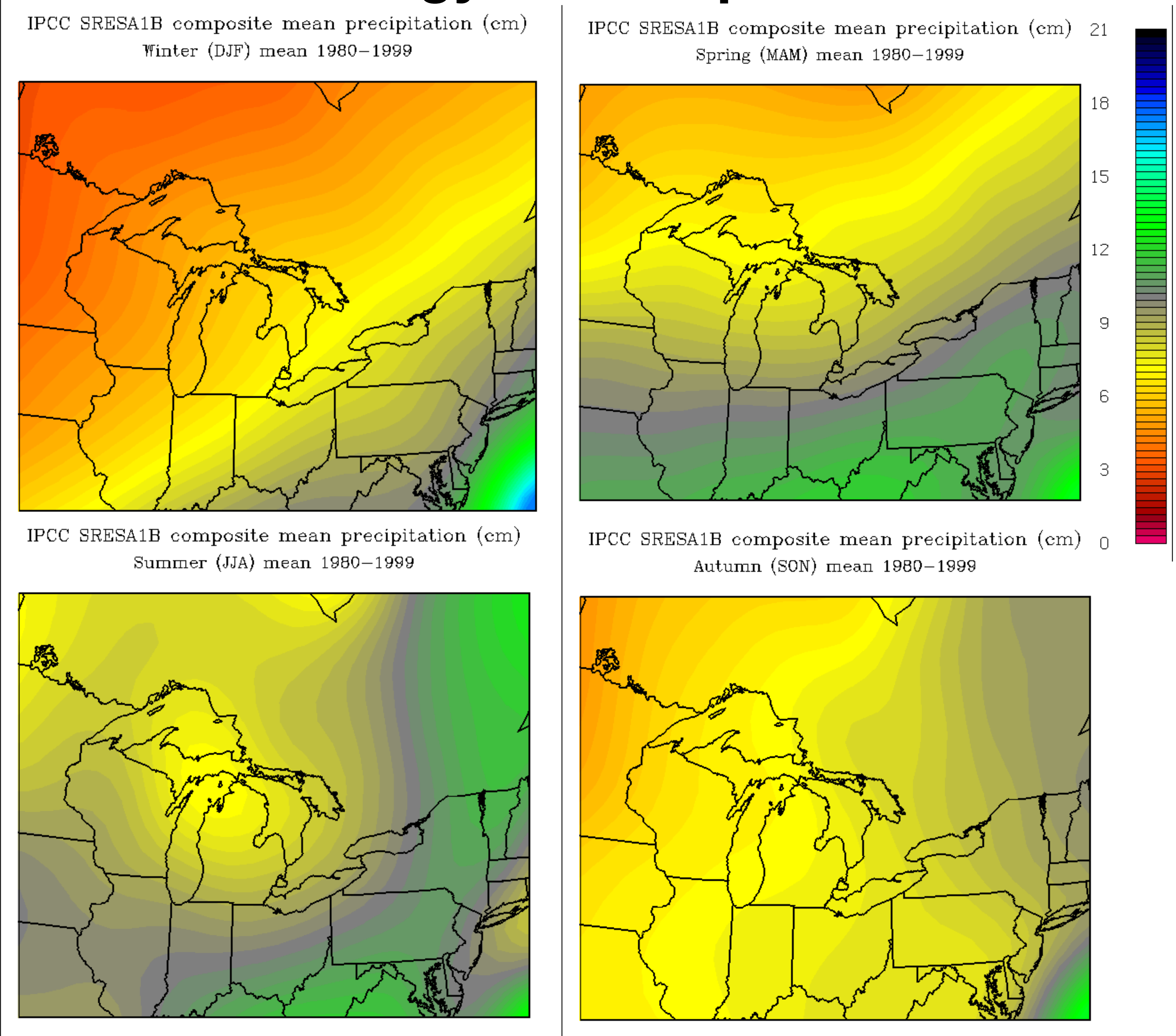
Spring ~3C

Summer ~3C

Autumn 3C

Ta rises most in winter and other seasons

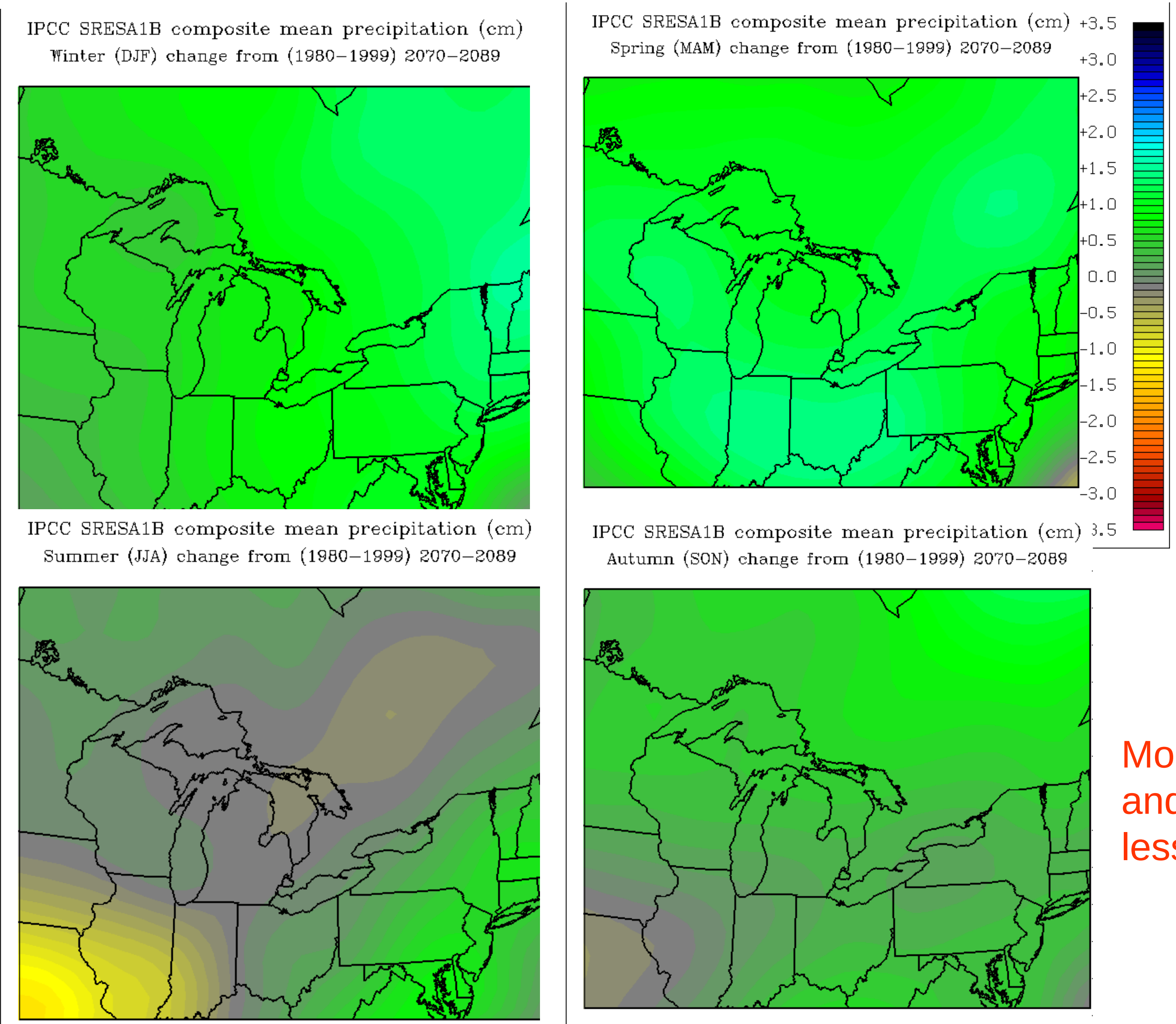
Climatology of Precip: 1980-1999



Winter Spring

Summer Autumn

Precip anomaly projection: 2070-2089



Winter Spring

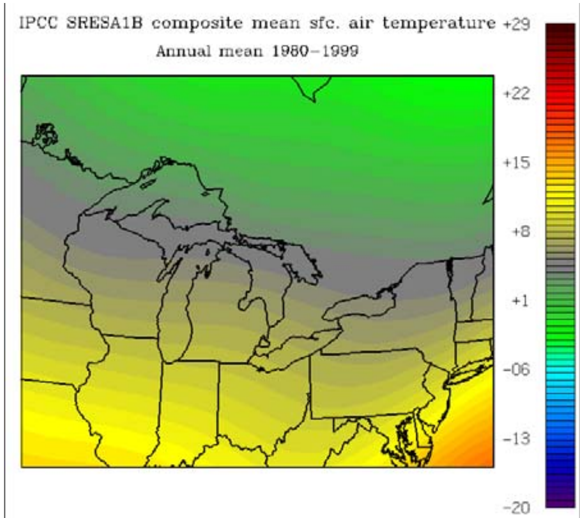
Summer Autumn

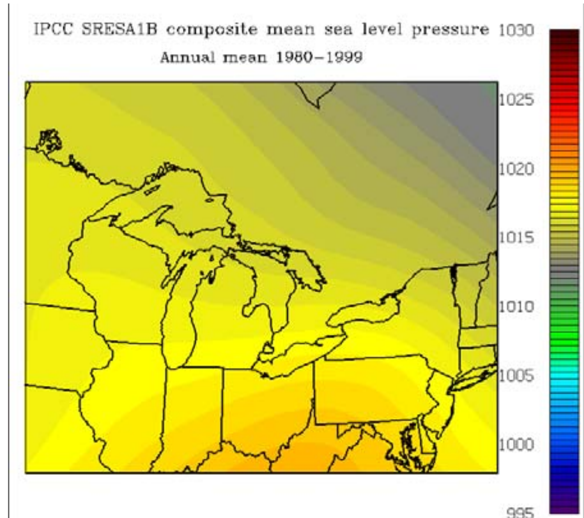
More precip. In winter and other seasons, but less precip. In summer

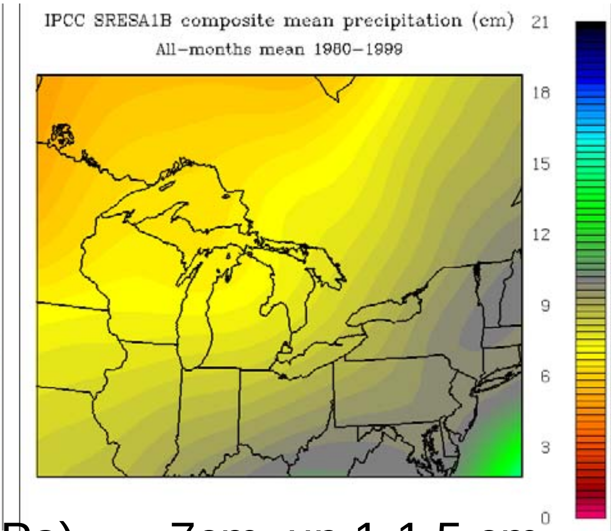
Summery of Annual Projection

Tair SLP Precip (monthly)

1980-1998







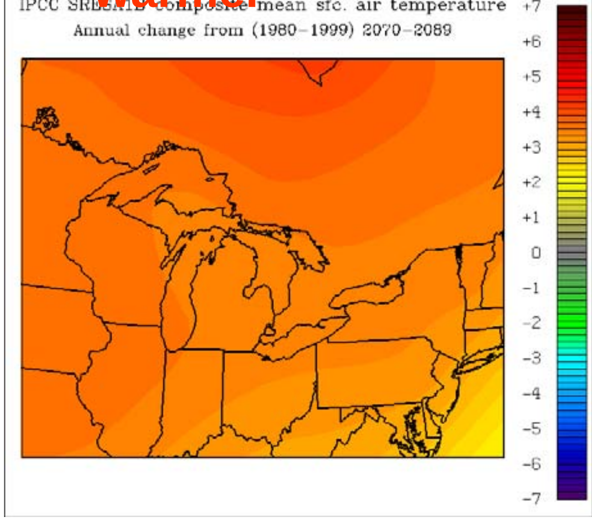
2-10C, up ~3C

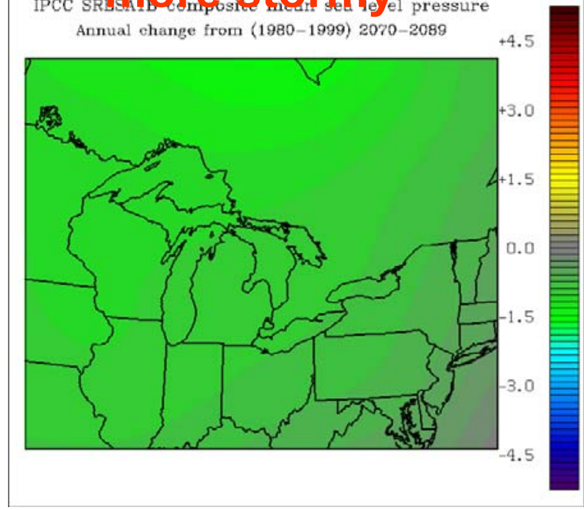
1015-1018 mb, down ~1.5mb (hPa)

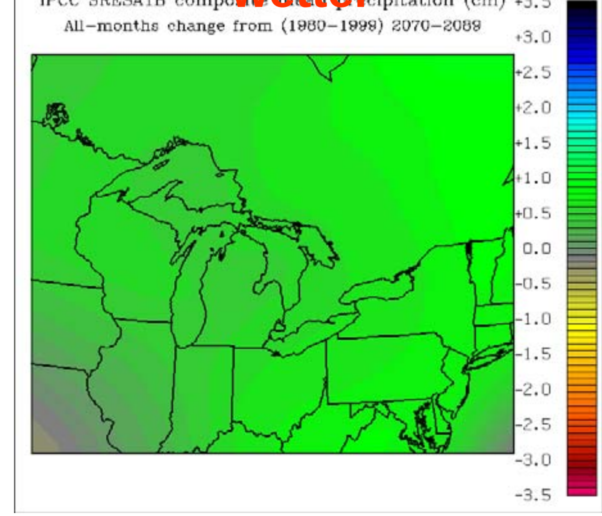
~7cm, up 1-1.5 cm

warmer **more stormy** **wetter**

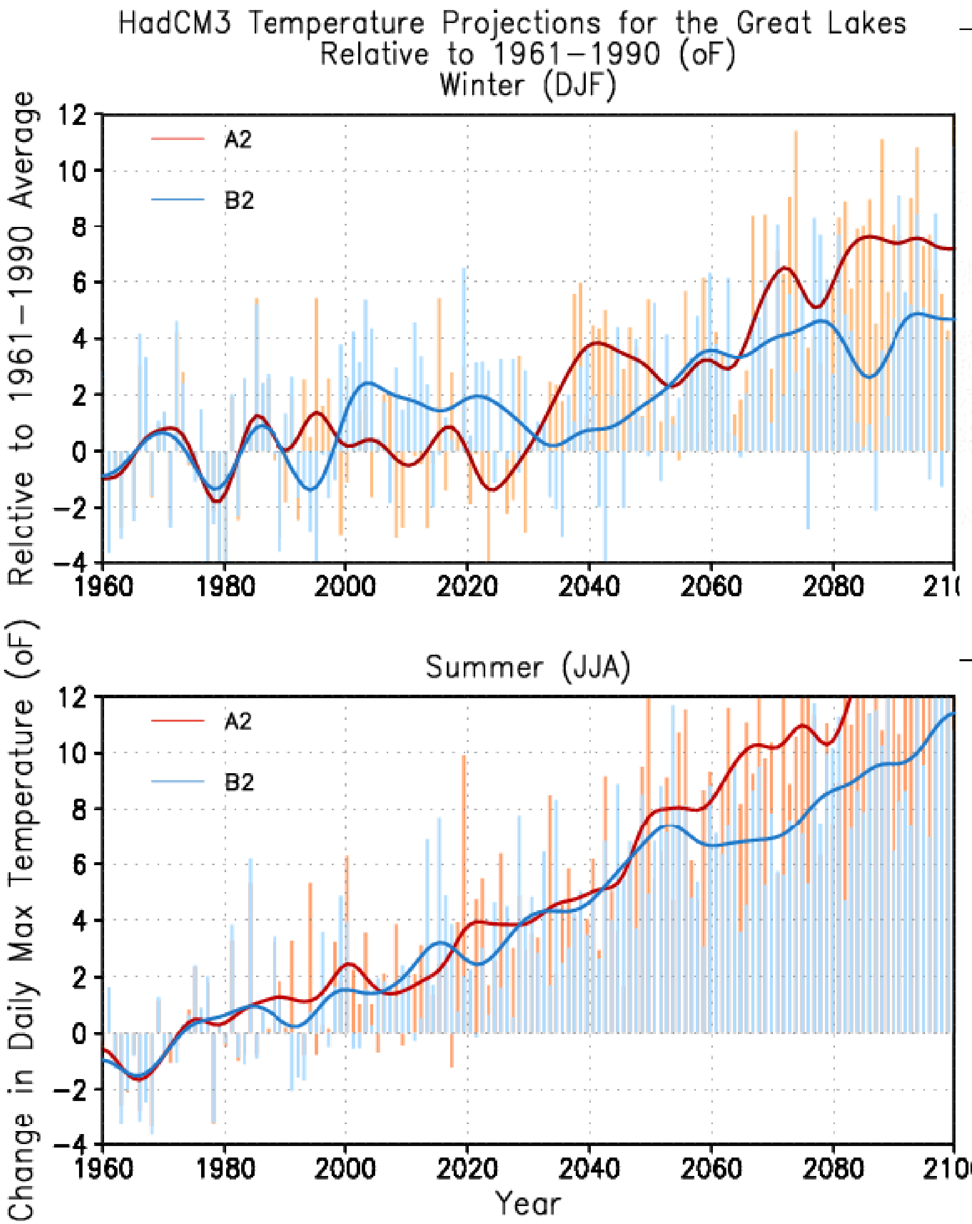
2070-2089

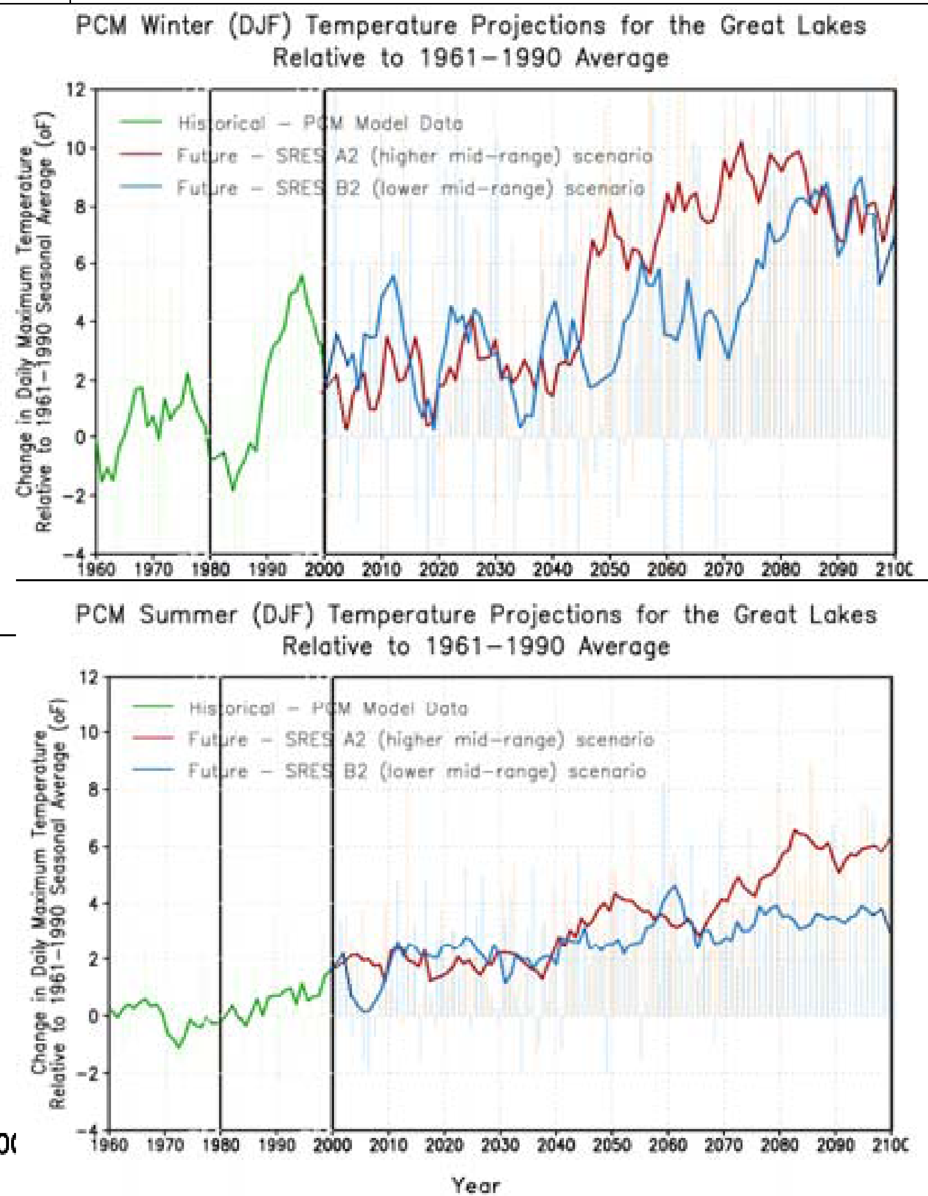




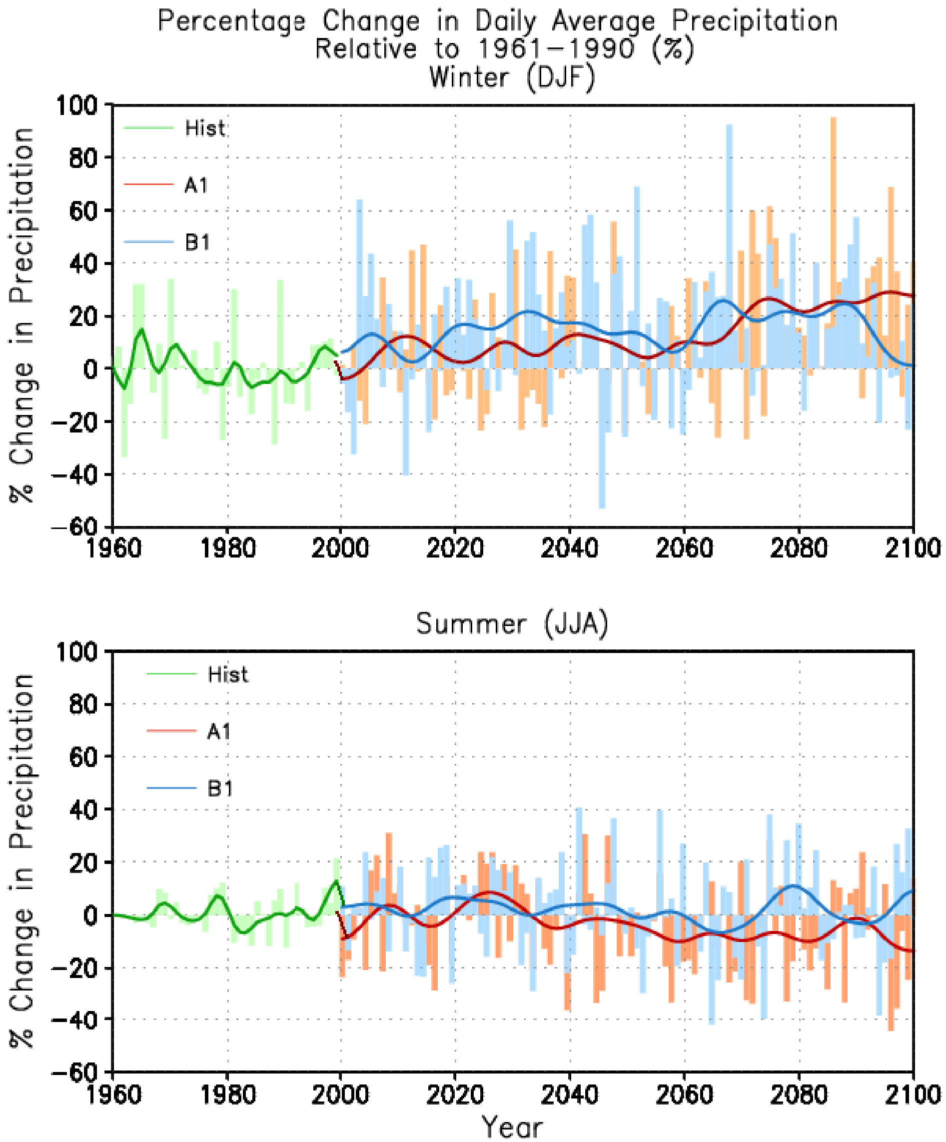


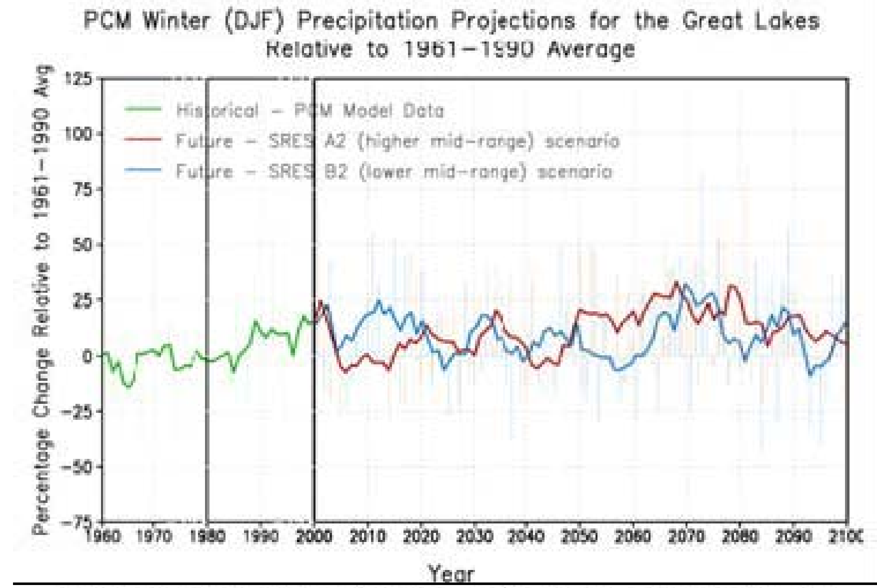
Comparison of HadCM3 and PCM temperature projections for winter (DJF) and sum (JJA). Temperature change is shown relative to 1961-1990 average for that season.

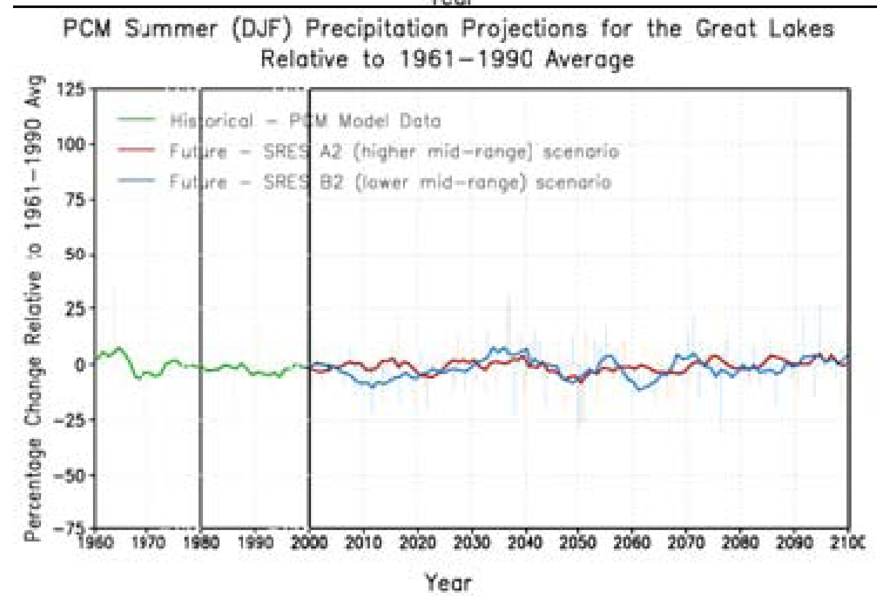




Comparison of HadCM3 and PCM projections of change in precipitation for winter (I and summer (JJA). Percentage change in precipitation is shown relative to 1961-199 f







Summary

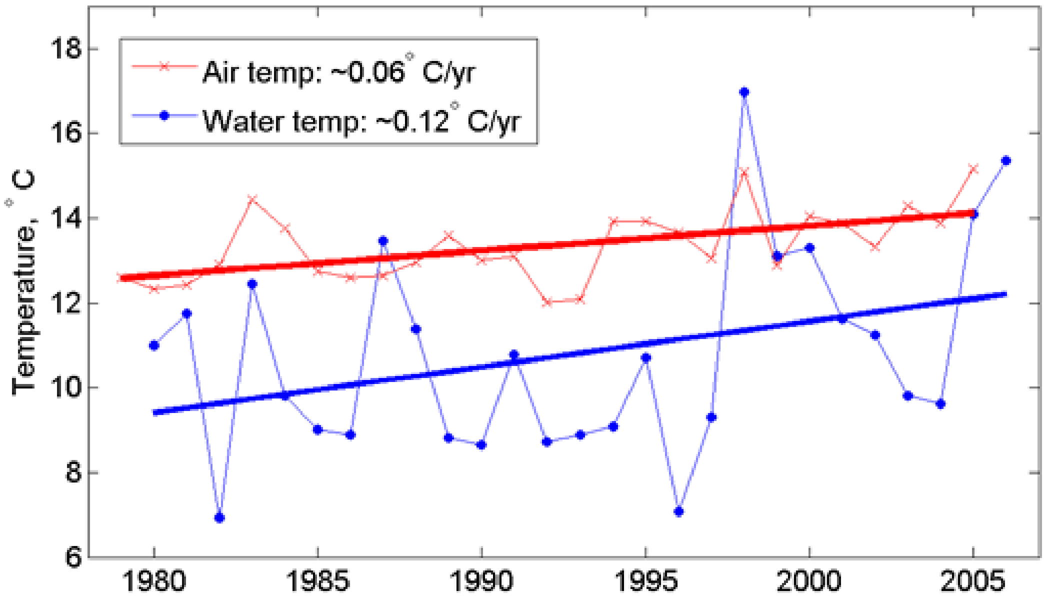
- **IPCC projects that by 2070-2089, the annual GL**

  Tair increases by ~3C, warmer weather

  SLP decreases by ~1.5 hPa (mbar) ➔ more cyclonic storms, and

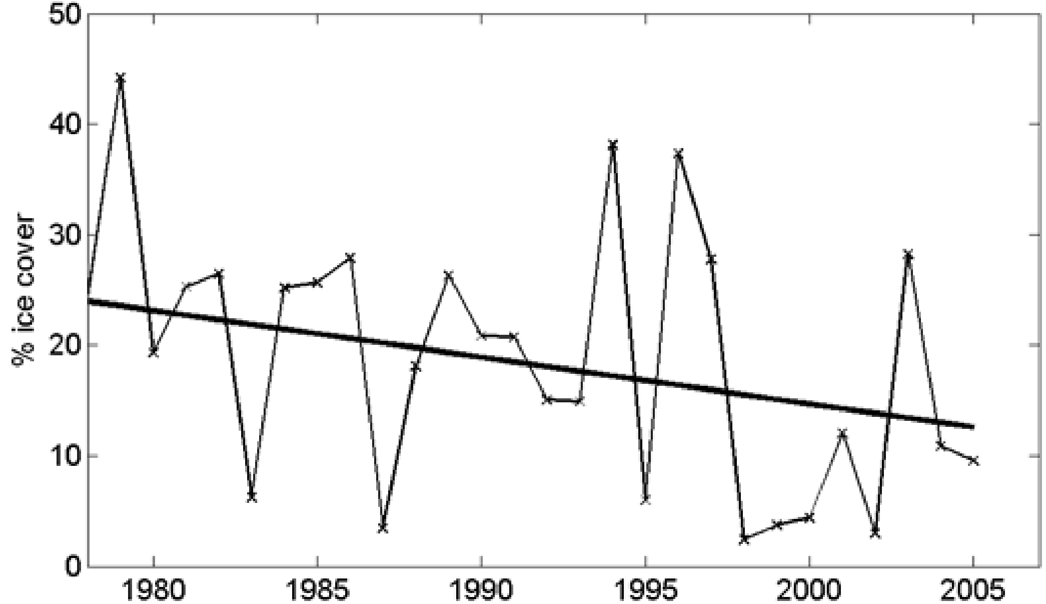
  Precip (monthly averaged) increases by ~1 cm➔ wetter weather, although summer Precip slightly decreases by 0.5 cm.

Interannual variability of the Great Lakes water temperature



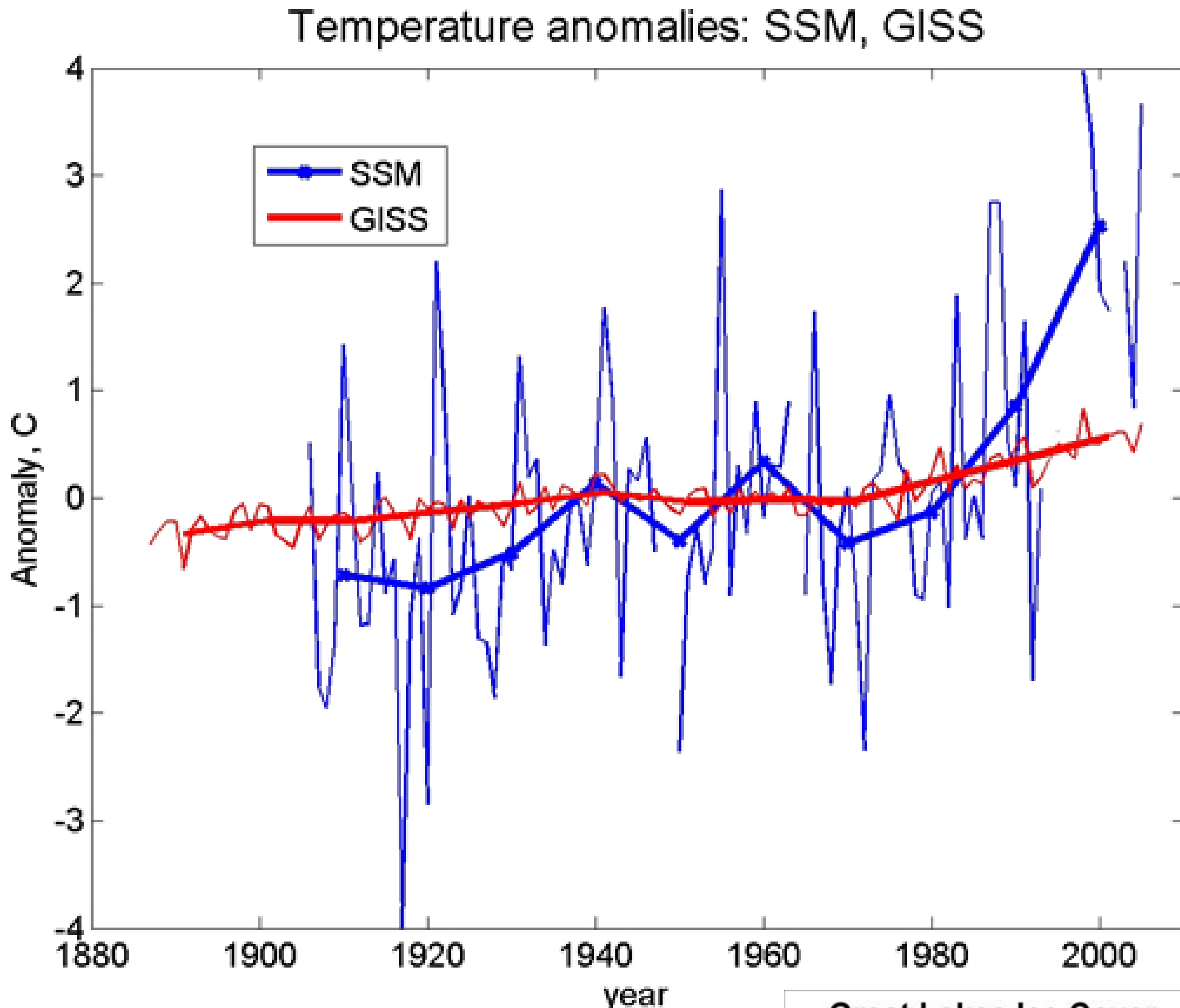
Upper: Lake Superior Ta (red) and Tw (blue) From Austin et al 2006)

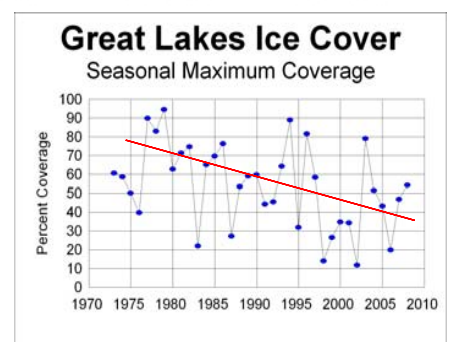
Upward trend (anthro-pagenic) and variability (natural)



Lower: Lake Superior Ice cover in %

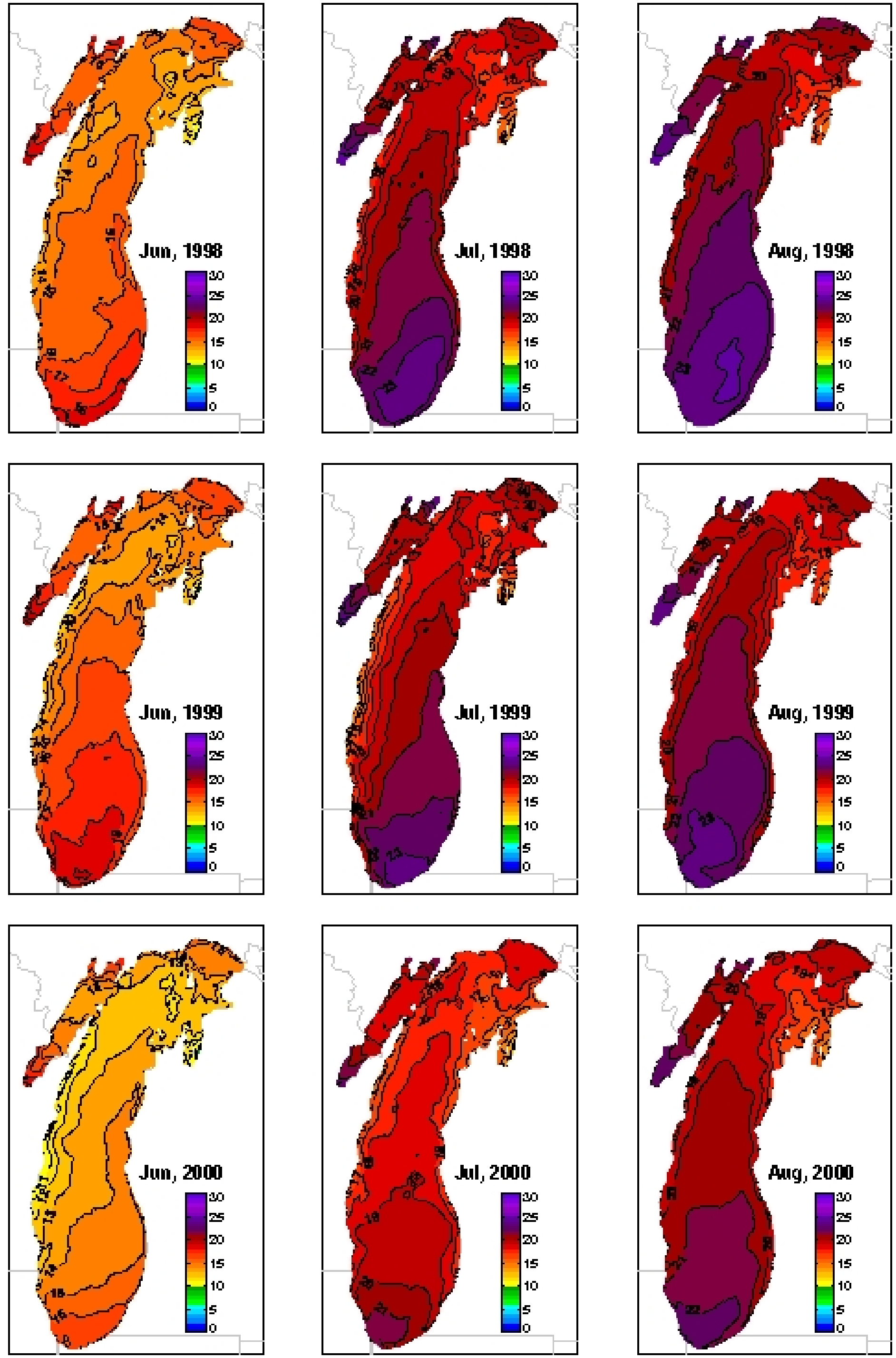
From Assel


Temperature anomalies: SSM, GISS
SSM
GISS
Anomaly, C
year
4
3
2
1
0
-1
-2
-3
-4
1880
1900
1920
1940
1960
1980
2000


Great Lakes Ice Cover
Seasonal Maximum Coverage
Percent Coverage
100
90
80
70
60
50
40
30
20
10
0
1970
1975
1980
1985
1990
1995
2000
2005
2010

Mean surface temperature in June, July, and August

(from Beletsky)

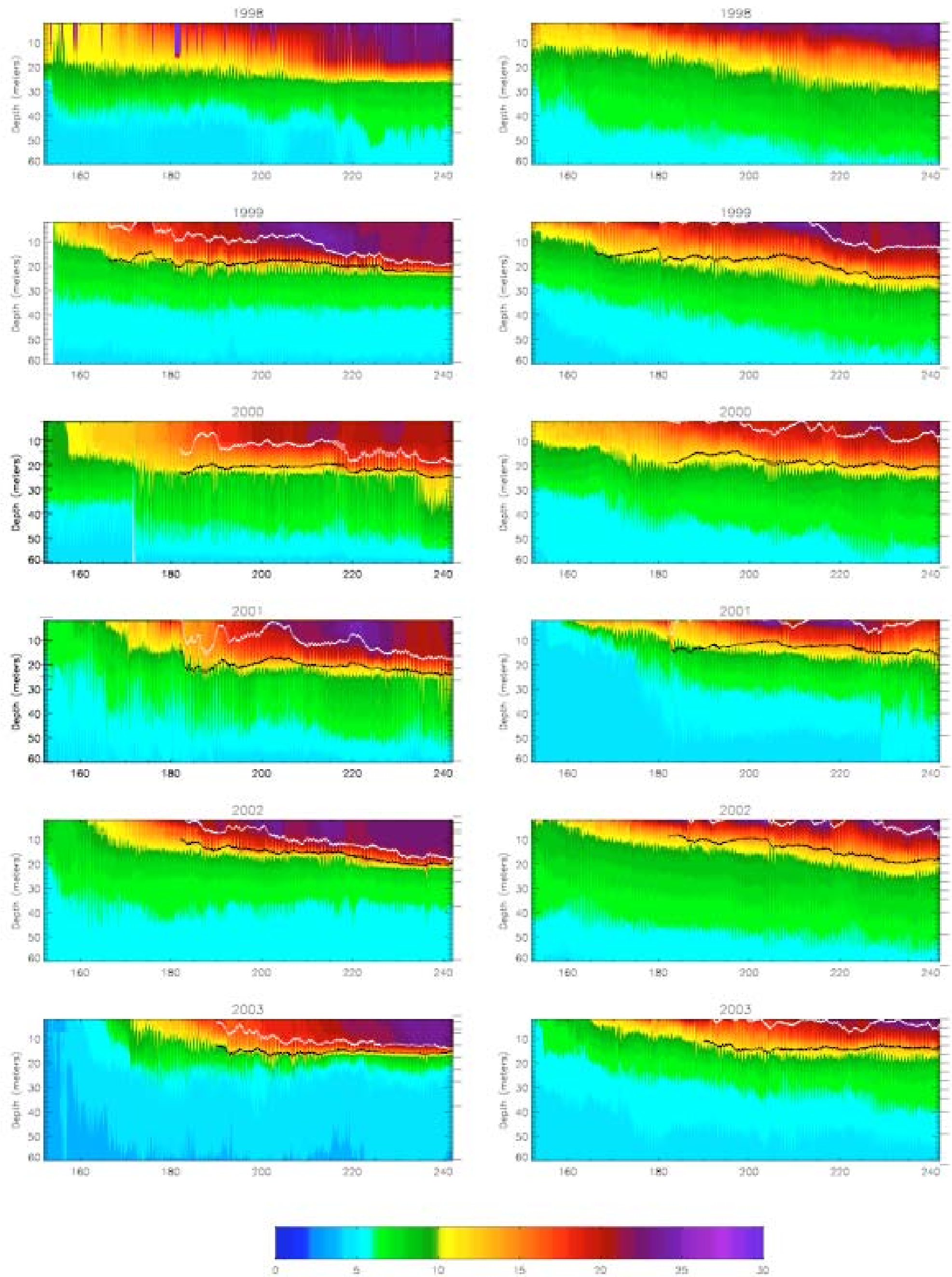


1998

1999

2000

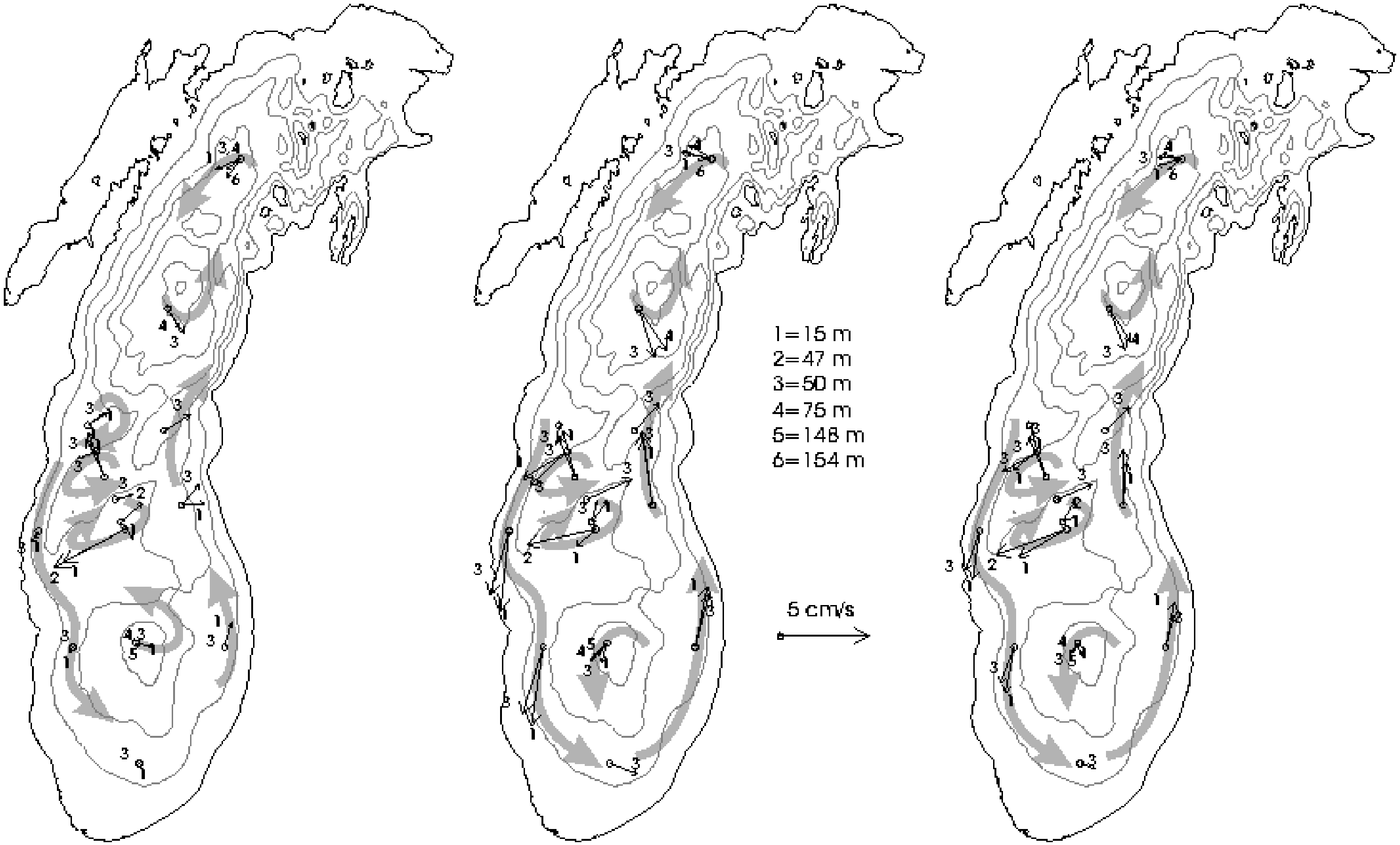
Observations Model



Interannual variability of time-depth T at 45007 (southern LM deepest basin) for 1998, 1999, 2000, 2001, 2002, and 2003

(from Beletsky, Schwab, and McCormick, 2006, JGR)

Observed Lake Michigan Currents, 1982-83 (Beletsky et al.,1999)

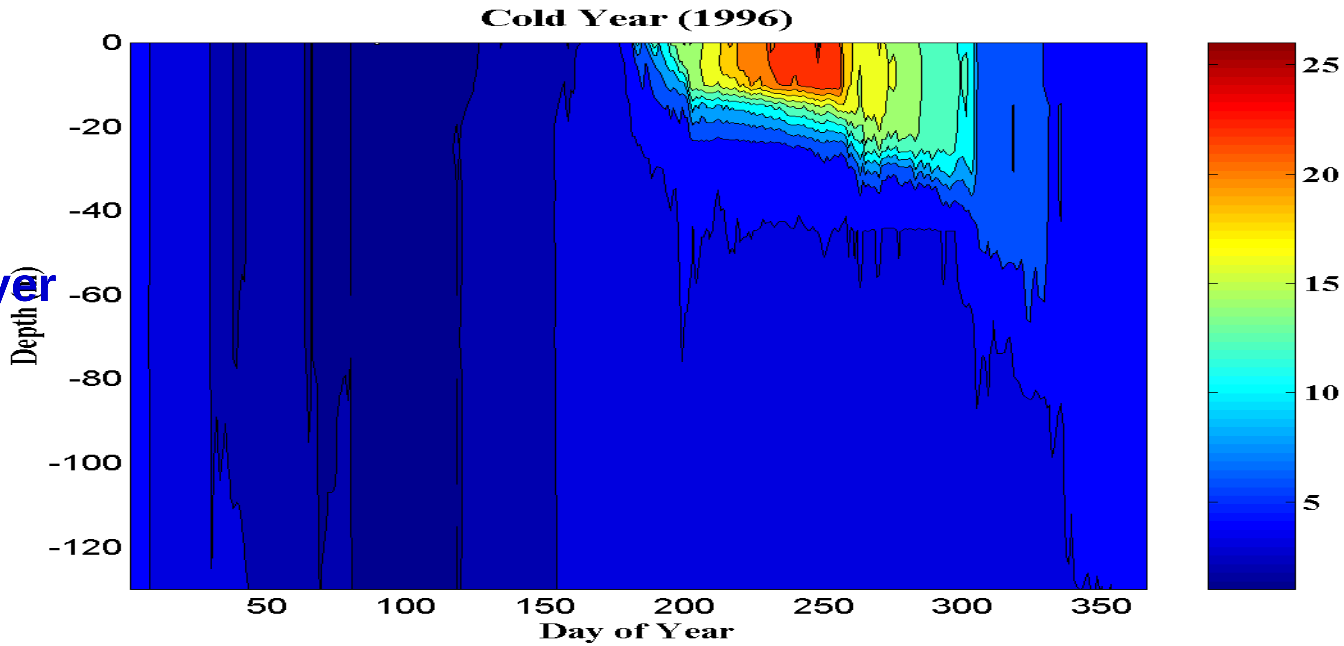


Summer Winter Annual

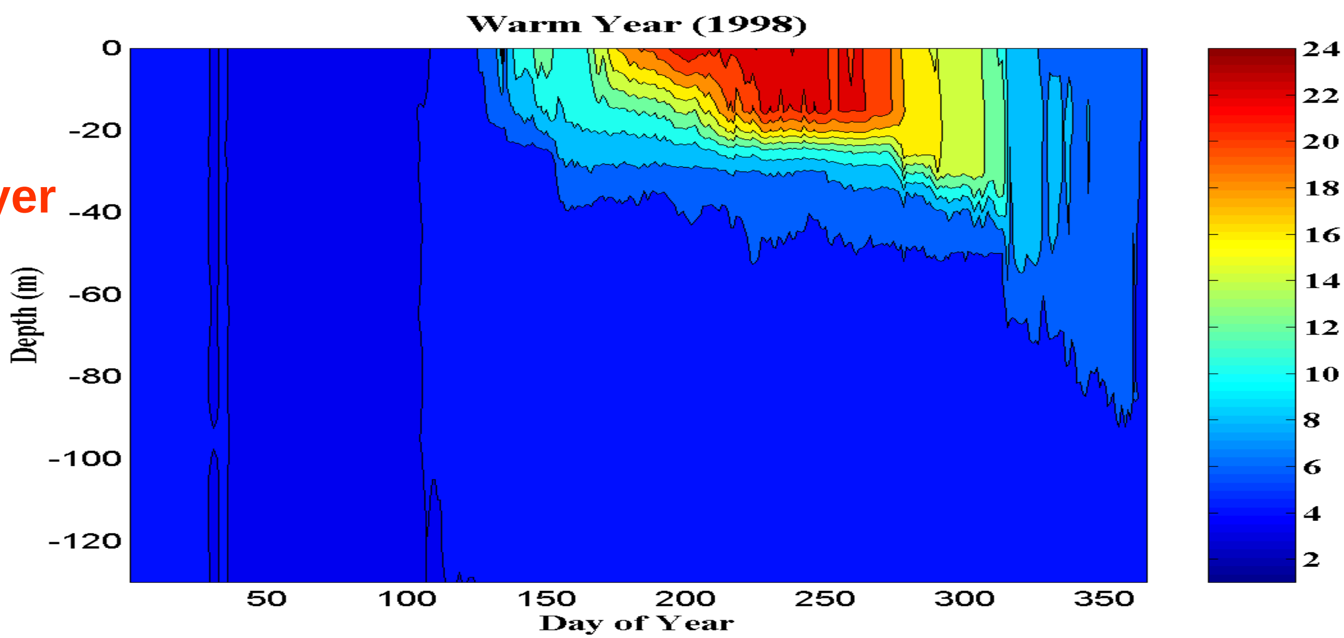
Ecosystem adaption

Mike McCormick's midlake thermistor chain

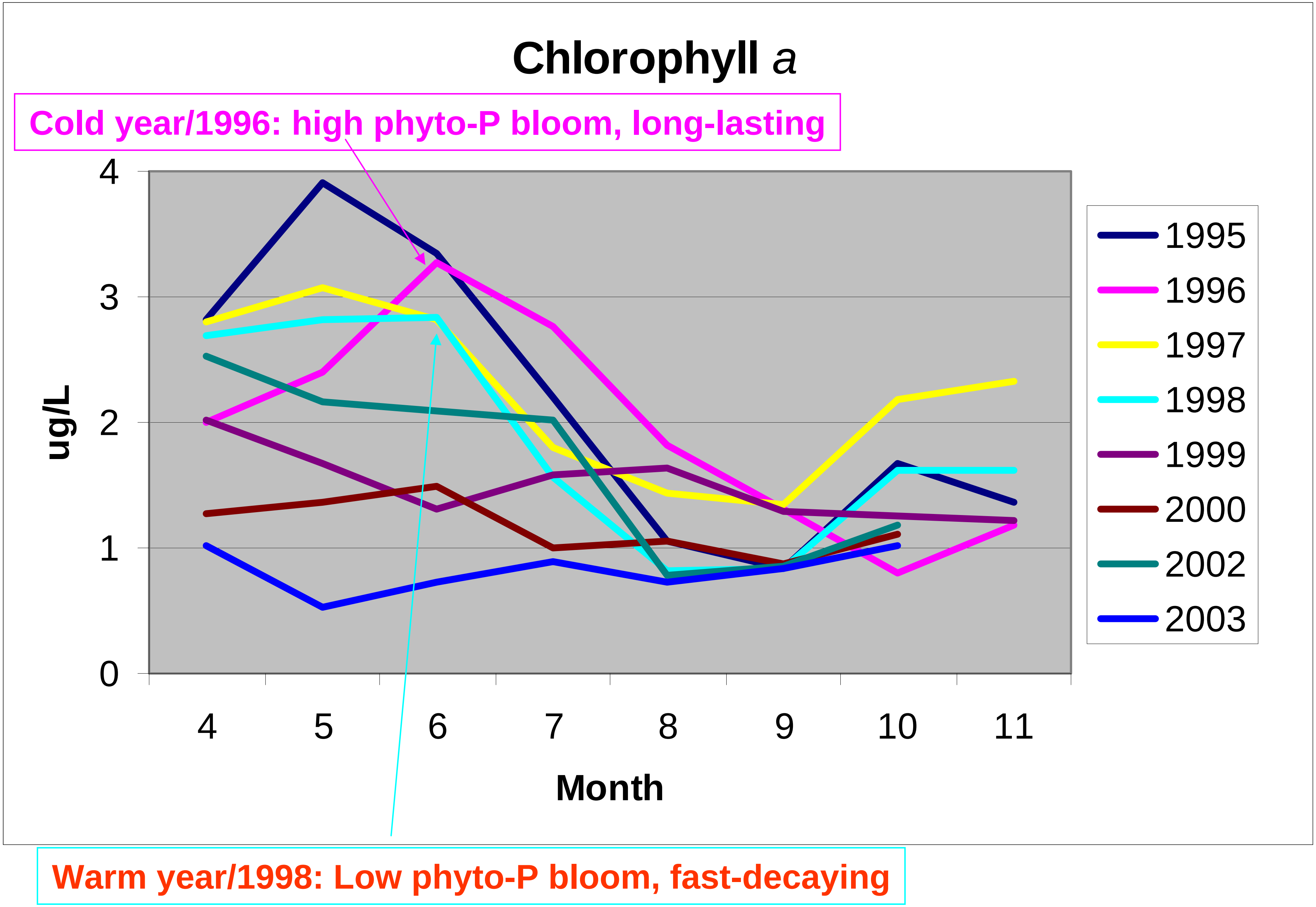
1996: Cold, shallow mixed-layer depth, short warming perid



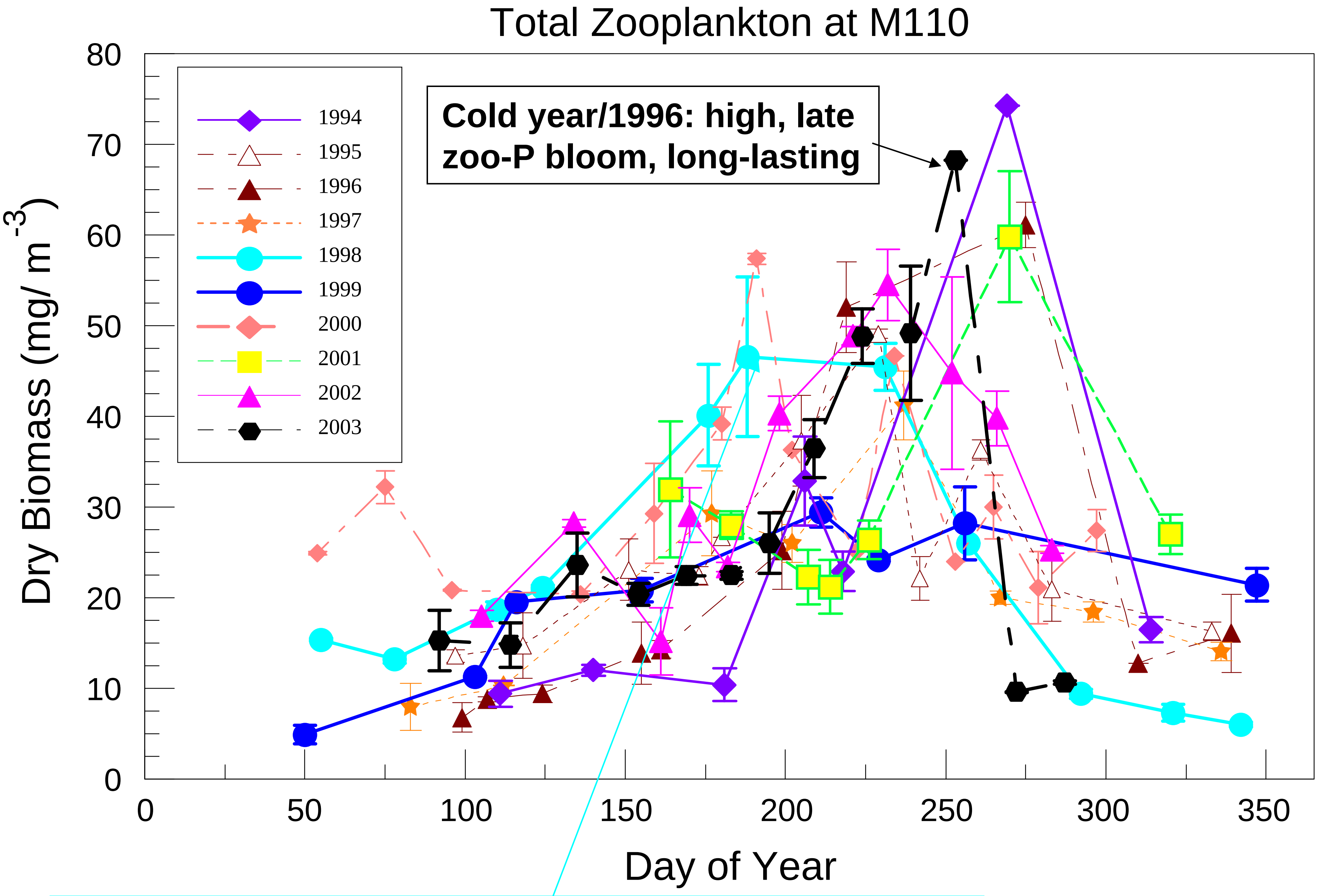
1998: Warm, deep mixed-layer depth, long warming period



By Henry Vanderploeg



By Henry Vanderploeg



Warm year/1998: Low, early zoo-P bloom, fast-decaying

Changes in Lake Michigan Plankton—Importance of time series

- Changes in long-term trends in chlorophyll maybe driven by changes in nutrient loading, invasive mussels, and maybe long-term changes in weather (i.e., climate)
- There are strong changes in thermal structure from year to year
- Changes in thermal structure result in big changes in zooplankton driven, in part, by temperature affecting recruitment of young fish that eat them (bottom-up effect)

Overall Summary

- The gap of lake ice modeling is being filled

- GL climate will get warmer, wetter, and stormier at the end of the 21st century: Adaption and correct policy making are needed to mitigate the impacts of the migrating climate

- GL water T got warmer and ice became less. The gap for downscaling modeling/projection of the 21st century GL climate using IPCC model forcing should be filled

- Ecosystems are adapting to the year-to-year change in water T of up to ~2 C. How to project the ecosystems' adaption to a Tw rise up to 4-5C in the Great Lakes?

  (the gap needs to be addressed using coupled lake-ice-ecosystems models driven by IPCC model forcing)